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NASA Conference Publication 3244

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Second NASA Workshop on Wiring for Space Applications

Proceedings of a workshop cosponsored by NASA Headquarters, Office of Safety and Mission Quality, and NASA Lewis Research Center, and held in Cleveland, Ohio, October 6–7, 1993

NASA

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NASA

National Aeronautics and Space Administration

Office of Management

Scientific and Technical Information Program

1994

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PREFACE

This document contains the proceedings of the Second NASA Workshop on Wiring for Space Applications held at NASA Lewis Research Center, Cleveland, Ohio, October 6-7, 1993. The workshop was sponsored by NASA Headquarters/Code QW Office of Safety and Mission Quality, Technical Standards Division and hosted by the NASA Lewis Research Center, Power Technology Division, Electrical Components and Systems Branch. The workshop addressed key technology issues in the field of electrical power wiring for space applications. Topics discussed included wiring insulation constructions, manufacturing technologies, and protection systems. In addition to reviewing the ongoing NASA and other related programs on space wiring, the workshop provided a forum in which the government and industry representatives could discuss the results of their research programs on the development of arc track-resistant wiring systems.

The workshop organizers express their appreciation to the session chairmen, speakers, and participants, whose efforts contributed to the technical success of this event. Thanks are also due to Ms. Billie Hurt, Ms. Ruth Clark, Ms. Barbara Coles, and Ms. Brunilda Quinones for their relentless efforts in providing a well prepared and very efficient and organized workshop.

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SECOND NASA WORKSHOP ON WIRING FOR SPACE APPLICATIONS

SUMMARY

The Second NASA Workshop on Wiring For Space Applications was held at NASA Lewis Research Center, Cleveland, Ohio, October 6-7, 1993. The workshop was sponsored by NASA Headquarters, Code QW, Office of Safety and Mission Quality, Technical Standards Division and hosted by LeRC's Power Technology Division, Electrical Components and Systems Branch. Like its predecessor, the First NASA Workshop on Wiring For Space Applications, which was also hosted by NASA Lewis on July 23-24, 1991, this workshop addressed key technology and development issues pertaining to electrical power wiring for space-based applications.

The workshop was organized into three sessions. Session I provided overviews of the NASA Office of Safety and Mission Quality, and the various ongoing programs on space wiring. These included the European Space Agency Wiring Program to understand the arc tracking phenomenon and develop detection techniques, the US Air Force Program to develop a 300°C wire insulation system for the aircraft environment, and the NASA Space Wiring Program to provide a technology base for the development of lightweight, arc track-resistant and reliable wiring systems for aerospace applications.

Session II discussed the role of the various organizations and programs involved in the qualification, certification, and standardization of electrical wiring. These included the NASA Goddard Space Flight Center Parts Project Office (NPPO), Naval Air Warfare Center (NAWC), and the National Electrical Manufacturers Association (NEMA). A survey of space wiring failures, the effects of improper wiring system design and installation, and the wiring requirements for the Space Station Freedom were also presented in this session.

Session III focused on the results of wiring tests performed by numerous organizations to address NASA's unique testing requirements. Experimental investigations on the effect of space environmental stresses on the performance of electrical wiring were presented and discussed. These stresses included atomic oxygen exposure, vacuum, ultraviolet radiation, high temperature, and low gravity. A proposed new test method for the assessment of arc tracking was also discussed and compared to the conventional testing techniques. Presentations were also given by industry representatives in this session on the state of the art development in the area of high temperature, high performance, arc track-resistant wiring insulation and dielectrics for aerospace applications. The workshop was attended by approximately 60 individuals from the United States, comprising government, industry, and academia and 3 visitors from Germany. A list of the attendees is included on page ix and the final workshop agenda is listed on page xii.

The general consensus of the workshop was that space wiring failures are of a major concern and are detrimental to mission safety and success. Among the issues that were identified and recommended for further investigation include the development of new arc track-resistant wiring insulation constructions, better system designs, adequate circuit protection, and proper handling procedures. These factors, when implemented, will certainly improve the reliability and lifetime of space power systems. It is anticipated that a better understanding of arc tracking in wiring insulations will be achieved through the NASA Wiring For Space Applications Program, in conjunction with the efforts of other agencies and organizations. The resulting database of information will help in the development of lightweight, safe, and reliable power systems with new wiring constructions which are resistant to arc tracking and suitable for use in aerospace applications.

The organizers once again express their appreciation to the volunteers and participants in making this workshop a very interesting and successful event. The support of NASA Headquarters Code QW for this program is gratefully acknowledged.

SECOND NASA WORKSHOP ON WIRING FOR SPACE APPLICATIONS

AGENDA

October 6 - 7, 1993
NASA Lewis Research Center
NASA Administration Building (Bldg. No. 3)
Auditorium

Wednesday, October 6

Session I: Organizations and Programs

Time	Topic	Speaker	Organization
8:30 - 8:45	Opening Remarks	R. Bercaw	NASA/LeRC
8:45 - 9:15	NASA Code Q Overview	D. Mulville	NASA/HQ/QE
9:15 - 9:45	Wiring for Space Applications	N. Schulze	NASA/HQ/QE
9:45 - 10:15	Break		
10:15 - 10:45	ESA Program Overview	H. Reher	MBB Deutsche Aerospace
10:45 - 11:15	Robust 300 C Wire Insulation System	J. Nairus	Wright Laboratory
11:15 - 11:30	Discussion		
11:30 - 12:30	Lunch		

Session II: Wiring Applications and Standards

Time	Topic	Speaker	Organization
12:30 - 1:00	NASA Wiring Program - Survey of NASA Experiences in Wiring System Safety	M. Stavnes	NASA/LeRC
1:00 - 1:30	SSF Wiring Requirements	D. Emerson	NASA/LeRC
1:30 - 2:00	NASA Parts Program Office Responsibilities	P. Kilroy	NASA/GSFC
2:00 - 2:30	NASA Parts Project Office - Basic Goals	J. Plante	NPPO/Paramax
2:30 - 3:00	Break		
3:00 - 3:30	NAVAIR Aircraft Wiring Standardization and Qualification Program	T. Meiner	NAWC
3:30 - 3:45	Organized Wiring Systems	T. Meiner	NAWC

3:45 - 4:15	NEMA Wire and Cable Standards Development Activities	R. Baird	NEMA
4:15 - 4:45	Inspection of Installed Wiring Systems	J. Landers	NASA/MSFC
6:00 - 7:00	Cash Bar		NASA/LeRC Main Cafeteria
7:00 - 9:00	Dinner		NASA/LeRC Main Cafeteria

Thursday, October 7

Session III: Wiring Test Results

Time	Topic	Speaker	Organization
8:30 - 9:00	NASA Wiring Program - Test Program	A. Hammoud	NASA/LeRC
9:00 - 9:30	Flammability, Odor, Outgassing, and Compatibility with Aerospace Fluids of Wire Insulation	D. Hirsch	Lockheed
9:30 - 10:00	Electrical and Mechanical Testing of Wire Insulation for Space Applications	L. Burkhardt	McDonnell Aerospace Co.
10:00 - 10:30	Evaluation of Pyrolysis and Arc Tracking on Candidate Wire Insulation for Space Applications	T. Stueber	NASA/LeRC
10:30 - 11:00	Break		
11:00 - 11:30	Wire Insulation Degradation and Flammability in Microgravity	R. Friedman	NASA/LeRC
11:30 - 12:00	Breakdown Testing of Wiring Insulation	J. Laghari	Univ. Buffalo
12:00 - 12:45	A New Test Method for the Assessment of Arc Tracking	D. König	Univ. Darmstadt
12:45 - 1:45	Organized Lunch Buffet		NASA/LeRC Main Cafeteria
2:00 - 2:30	High Temperature Polymer Dielectric Film Insulation	R. Jones	TRW
2:30 - 3:00	High Temperature, Arc Track Resistant Aerospace Insulation	W. Dorogy	Foster Miller, Inc.
3:00 - 3:30	3M High Temperature Dielectric Film	E. Hampl	3M Co.
3:30 - 4:00	Closing Remarks/Discussions	R. Bercaw	NASA/LeRC

SESSION I

ORGANIZATIONS AND PROGRAMS

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NASA CODE Q OVERVIEW

Daniel Mulville
NASA Headquarters
Washington, DC

OVERVIEW

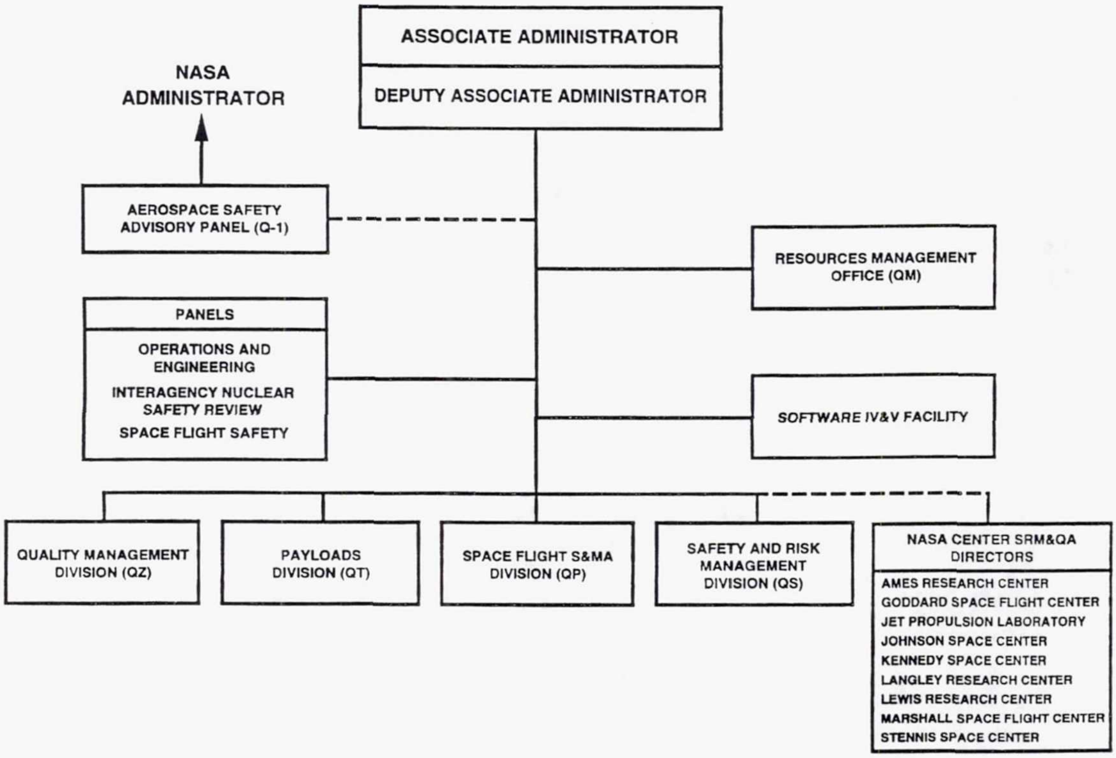
- CODE Q ORGANIZATION
- CODE Q VISION AND MISSION
- CODE QW MISSION AND KEY ACTIVITIES
- MAJOR APPLIED TECHNOLOGY PROJECTS

NASA CODE Q OVERVIEW

OFFICE OF SAFETY AND MISSION ASSURANCE

- CHARTER
  - NMI 1103.39E, APRIL 9, 1993
- VISION
  - WE ARE RECOGNIZED AS AN INTERNATIONAL LEADER IN THE SAFETY, QUALITY, AND MISSION ASSURANCE OF U.S. AERONAUTICS AND SPACE PROGRAMS
- MISSION
  - PROVIDE LEADERSHIP IN THE DEVELOPMENT AND OPTIMIZATION OF SAFETY AND MISSION ASSURANCE POLICIES, STRATEGIES, AND TECHNOLOGIES FOR NASA PROGRAMS. ADVOCATE A SYSTEMATIC AND DISCIPLINED APPROACH FOR ACHIEVING SAFETY AND MISSION SUCCESS AND SUPPORTING THE TECHNICAL RISK DECISION-MAKING PROCESS

OFFICE OF SAFETY AND MISSION ASSURANCE (CODE Q)



ENGINEERING AND QUALITY MANAGEMENT DIVISION

MISSION: ***DEVELOP AND ESTABLISH AND INTEGRATED ENGINEERING AND QUALITY MANAGEMENT CAPABILITY TO ENHANCE THE QUALITY OF NASA MISSIONS***

KEY ACTIVITIES:

- **ESTABLISH ENGINEERING AND QUALITY MANAGEMENT POLICY AND GUIDANCE FOR NASA PROGRAMS**
- **ENHANCE NASA'S ASSURANCE CAPABILITY THROUGH DEVELOPMENT OF IMPROVED ENGINEERING ANALYSIS, TEST, AND QUALIFICATION METHODS**
- **ESTABLISH NASA-WIDE ENGINEERING AND QUALITY STANDARDS, PRACTICES, AND PROCESSES TO SUPPORT DESIGN, MANUFACTURE, TEST, AND ASSURANCE OF FLIGHT SYSTEMS**
- **DEVELOP SYSTEMS ENGINEERING PRACTICES, TOOLS, AND METHODS TO IMPROVE NASA'S PROGRAM/PROJECT MANAGEMENT PROCESS**
- **UTILIZE ASSURANCE TECHNOLOGIES TO IMPROVE RELIABILITY AND PERFORMANCE OF FLIGHT PROJECTS (e.g., NDE, EEE PARTS AND PACKAGING, MECHANICAL PARTS, AEROSPACE BATTERIES, WIRING)**
- **ENHANCE QUALITY ASSURANCE SKILLS DEVELOPMENT AND TRAINING PROGRAMS**

MAJOR PROGRAM ELEMENTS

- ENGINEERING STANDARDS AND PRACTICES
  - POLICY AND STANDARDS
  - ENGINEERING CAPABILITY ENHANCEMENT
  - STRUCTURAL INTEGRITY
  - METRIC TRANSITION
- SOFTWARE ENGINEERING AND ASSURANCE
  - POLICY STANDARDS, METHODS, PROCESSES
  - INDEPENDENT VERIFICATION AND VALIDATION (IV&V)
  - PROGRAM ASSESSMENTS
- SYSTEMS ENGINEERING AND MANUFACTURING
  - STANDARDS AND GUIDELINES
  - PROGRAM DEVELOPMENT LIFE CYCLE
  - PRODUCT DATA EXCHANGE INITIATIVE
  - MANUFACTURING PROCESS IMPROVEMENT

MAJOR PROGRAM ELEMENTS (CONT.)

- EEE PARTS AND ELECTRONIC PACKAGING
  - POLICY AND STANDARDS
  - EEE PARTS CONTROL PROCESSES
  - PARTS AND PACKAGING TECHNOLOGY
  - NASA/ARPA RELTECH PACKAGING PROGRAM
- APPLIED TECHNOLOGY
  - AEROSPACE FLIGHT BATTERY SYSTEMS
  - AEROSPACE WIRING
  - PYROTECHNIC ACTUATED SYSTEMS
  - INTERFEROMETRIC FIBEROPTIC GYROSCOPE

APPLIED TECHNOLOGIES

- GOAL:
  - ENHANCE SAFETY, RELIABILITY, QUALITY, AND PERFORMANCE OF NASA's SPACECRAFT SYSTEMS

- OBJECTIVES:
  - DEVELOP IMPROVED TECHNOLOGIES FOR NASA FLIGHT PROGRAMS
  - IMPROVE TOOLS AND METHODS FOR ENGINEERING ANALYSIS
  - DEVELOP DATA BASES TO SUPPORT APPLICATIONS
  - PERFORM FLIGHT QUALIFICATION FOR ADVANCED TECHNOLOGY
    - PYROTECHNIC DEVICES (LASER INITIATED)
    - INTERFEROMETRIC FIBEROPTIC GYROSCOPE

APPLIED TECHNOLOGIES

FY 1993 DELIVERABLES

- DRAFT SPECIFICATION FOR LASER INITIATED SAFE AND ARM
- PYROTECHNIC SYSTEMS SPECIFICATION GUIDELINE
- DRAFT PYROTECHNIC SYSTEMS CATALOG
- DESIGN CONCEPTS FOR NASA STANDARD GAS GENERATOR
- NASA WIRING APPLICATIONS REQUIREMENTS (INTERIM)
- WIRING INSULATION TEST PLAN
- INTERFACE CONTROL DOCUMENT FOR FIBEROPTIC GYRO

WIRING FOR SPACE APPLICATIONS

Norman Schulze
NASA Headquarters
Washington, DC

BACKGROUND

- NEW FAILURE MODES WERE REPORTED IN WIRING SYSTEMS IN AIRCRAFT AND SPACE VEHICLES DUE TO DEGRADATION OF WIRING INSULATION

BACKGROUND

ARC TRACKING PHENOMENON

- PROCESS:
  - INITIATION OF ARC
  - PYROLYSIS OF INSULATION
  - ARC PROPAGATION
- FACTORS:
  - POWER LEVEL
  - FREQUENCY
  - INSULATION TYPE
  - ENVIRONMENT
- RESULT:
  - SYSTEM SHUT DOWN AND POSSIBLE LOSS OF MISSION

Background

Space Missions with Electrical Wiring System Failures

Mission	Cause	Result
Gemini 8	Electrical Wiring Short	Shortened Mission - Near Loss of Crew
Apollo 204	Damaged Insulation, Electrical Spark, 100% O_2	Fire, 3 Astronauts Lost
Apollo 13	Damaged Insulation/Short Circuit/Flawed Design	Oxygen Tank Explosion, Mission Incomplete
STS - 6	Abrasion of Insulation/Arc Tracking	Wire Insulation Pyrolysis 6 Conductors Melted
STS - 28	Damaged Insulation/Arc Tracking	Teleprinter Cable Insulation Pyrolysis
Magellan	Wrong Connection, Wiring Short	Wiring Insulation Pyrolysis - Ground Processing
Spacelab	Damaged Insulation/Arc Tracking	Wiring Insulation Pyrolysis During Maintenance
Delta 178/GOES-G	Mechanical or Electrochemical Insulation Damage	Loss of Vehicle
ESA - Olympus	Electrical Wiring Short	Loss of Solar Array

ONGOING EFFORTS

R&D PROGRAMS

- SYSTEM DESIGN
- DIFFERENT CONSTRUCTIONS
- NEW INSULATION
- PROTECTION TECHNIQUES
- QUALITY CONTROL

ORGANIZATIONS:

- NASA
- DOD LABS
- AEROSPACE INDUSTRY
- ACADEMIA
- ESA
- QUAL. & STAND. COMMITTEES

NASA Electrical Power Wiring Program

Workshop on Wiring for Space Applications
held at NASA LeRC, July 23-24, 1991

ATTENDEES

GOVERNMENT

NASA: HQ
LeRC
JSC
MSFC
KSC
GSFC
WSTF

Wright Patterson AFB

NRL

Naval Air Systems Command

INDUSTRY AND ACADEMIA

Boeing

E.I. Dupont, Co.

Lawrence Technologies

Foster Miller Inc.

Engineering Teledyne Thermatics

Allied - Apical

Auburn University

Rockwell International

Teledyne Thermatics

McDonnell Aircraft Co.

TRW

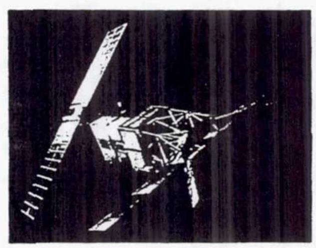
Aerospace Business Development Association

Westinghouse Electric Co.

University of Buffalo

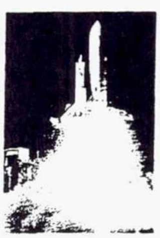
ELECTRICAL POWER WIRING PROGRAM

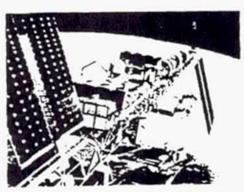
GOAL: TO PROVIDE A TECHNOLOGY BASE FOR THE DEVELOPMENT OF LIGHTWEIGHT, ARC TRACK-RESISTANT AND RELIABLE WIRING SYSTEMS FOR AEROSPACE APPLICATIONS.



APPROACH

- IDENTIFY MISSION REQUIREMENTS AND APPLICATION ENVIRONMENTS
- EVALUATE POTENTIAL WIRING SYSTEMS AND ESTABLISH A DATABASE
- INVESTIGATE ADVANCED TECHNOLOGIES RELEVANT TO WIRING FAILURE PREVENTION, DETECTION, AND ISOLATION.
- ESTABLISH GUIDELINES AND RECOMMENDATIONS



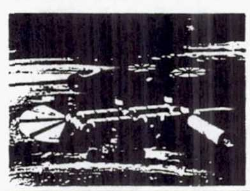


TECHNOLOGICAL DEVELOPMENTS

- NEW INSULATING MATERIALS
- NEW WIRING CONSTRUCTIONS
- IMPROVED SYSTEM DESIGN
- ADVANCED CIRCUIT PROTECTION

APPLICATIONS

- PRESSURIZED MODULES
- TRANS-ATMOSPHERIC VEHICLES
- LEO/GEO ENVIRONMENTS
- LUNAR AND MARTIAN ENVIRONMENTS



PROGRAM ORGANIZATION

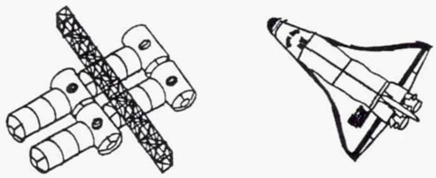
- TOP LEVEL MANAGEMENT BY NASA HEADQUARTERS, OFFICE OF SAFETY AND MISSION QUALITY, TECHNICAL STANDARDS DIVISION (CODE QW).
  - TECHNICAL MANAGEMENT BY THE NASA LEWIS RESEARCH CENTER, ELECTRICAL COMPONENTS AND SYSTEMS BRANCH, POWER TECHNOLOGY DIVISION.
    - PARTICIPATION BY OTHER NASA CENTERS, OTHER GOVERNMENT AGENCIES, INDUSTRY, AND ACADEMIA.

Wiring for Space Applications

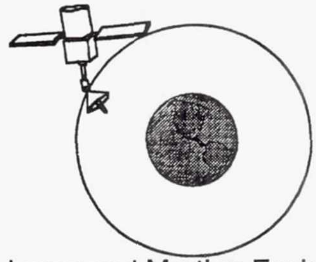
- Task #1: NASA Applications Requirements
- Task #2: Insulation Testing and Analysis
- Task #3: Wiring Systems Technology

NASA Mission Applications Environments

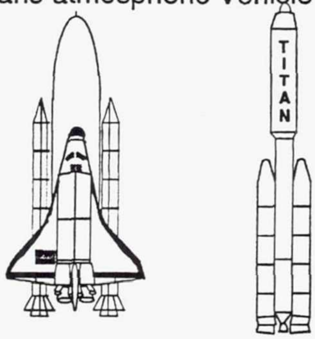
Pressurized Module Environments



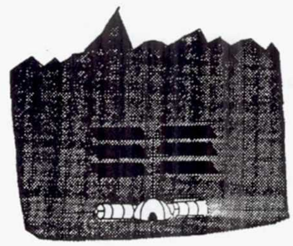
LEO/GEO Environments



Trans-atmospheric Vehicle Environments



Lunar and Martian Environments



Task #1. NASA Applications Requirements

OBJECTIVE

Identify NASA requirements and application environments and relate these to previous wiring studies.

APPROACH

- **Identify the environmental and operational conditions for various NASA missions.**
- **Establish a database on wiring based on previous and current wiring studies.**
- **Develop mission requirements and determine NASA unique test requirements.**

TASK #1 NASA APPLICATIONS REQUIREMENTS

- **REPORT "OPERATIONAL ENVIRONMENTS FOR ELECTRICAL POWER WIRING ON NASA SPACECRAFT"**

- **REVIEW**

  - NASA
  - DOD
  - INDUSTRY

- **PUBLICATION**

NASA WIRING PROGRAM

PUBLICATIONS

"EVALUATION OF DIELECTRIC FILMS FOR AEROSPACE AND SPACE POWER WIRING INSULATION," PAPER PRESENTED AT THE IEEE INTERNATIONAL SYMPOSIUM ON ELECTRICAL INSULATION, BALTIMORE, MARYLAND, MAY, 1992.

"WIRING FOR AEROSPACE APPLICATIONS," PAPER PRESENTED AT THE POWER ELECTRONICS SPECIALIST CONFERENCE, TOLEDO, SPAIN, JULY, 1992.

"NASA REQUIREMENTS AND APPLICATIONS ENVIRONMENTS FOR ELECTRICAL POWER WIRING," PAPER PRESENTED AT THE INTERSOCIETY ENERGY CONVERSION ENGINEERING CONFERENCE, SAN DIEGO, CALIFORNIA, AUGUST, 1992.

"AN ANALYSIS OF WIRING SYSTEM SAFETY IN SPACE POWER SYSTEMS," PAPER PRESENTED AT THE INTERSOCIETY ENERGY CONVERSION ENGINEERING CONFERENCE, ATLANTA, GEORGIA, AUGUST, 1993.

NASA WIRING PROGRAM

PRESENTATIONS

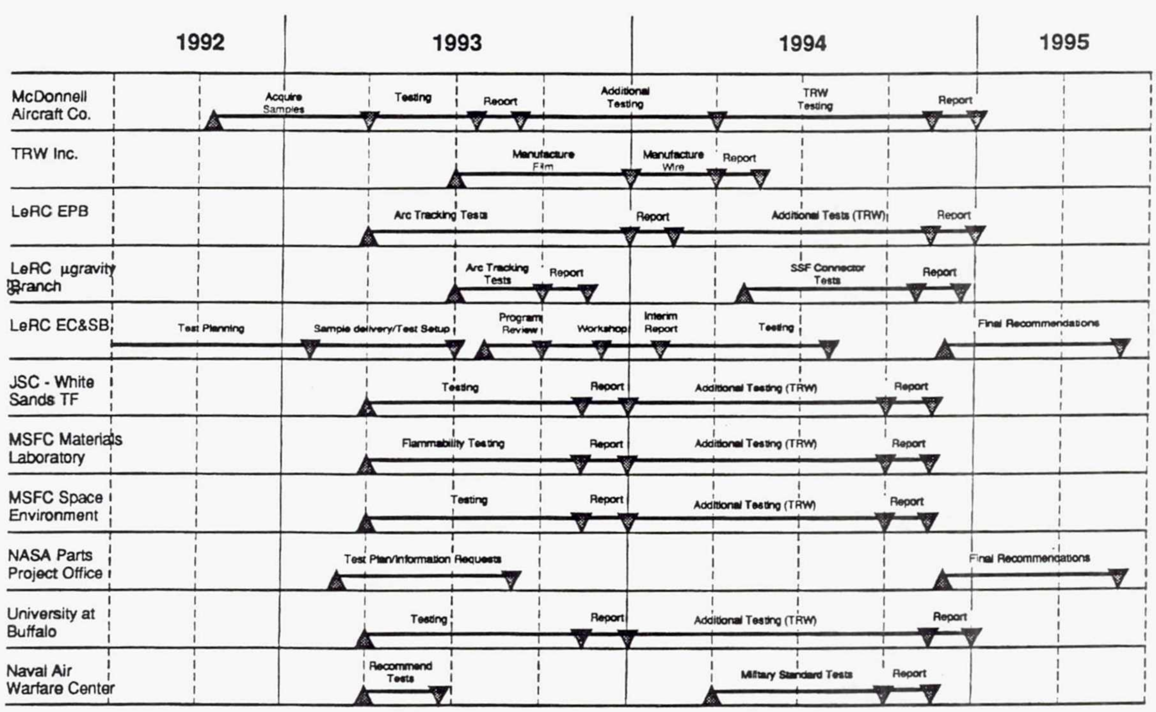
"WIRING FOR AEROSPACE APPLICATIONS-PROGRAM DESCRIPTION," PRESENTATION TO NASA GSFC (NPPO), MAY, 1992.

"WIRING FOR AEROSPACE APPLICATIONS-PROGRAM DESCRIPTION," PRESENTATION TO NASA MSFC, MAY, 1992.

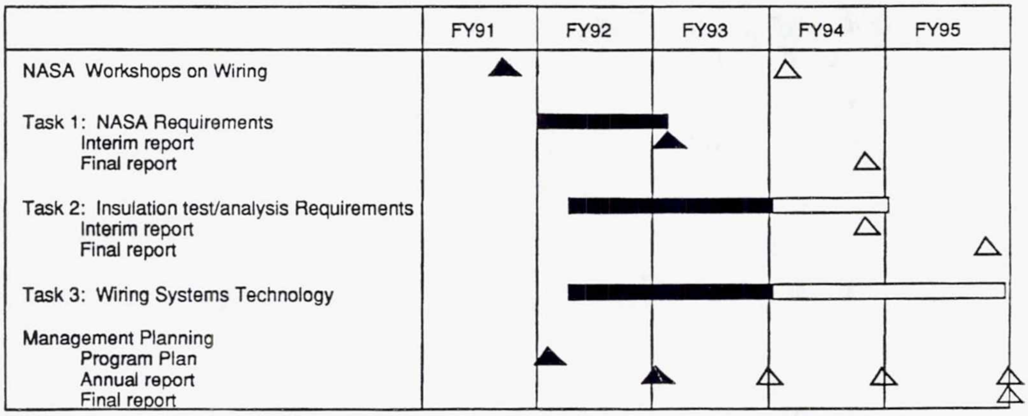
"WIRING FOR AEROSPACE APPLICATIONS-PROGRAM DESCRIPTION AND STATUS REPORT," PRESENTED AT THE NASA INTERCONNECTION STANDARDIZATION WORKING GROUP FALL CONFERENCE, NASA JSC, OCTOBER, 1992.

"ARC TRACKING TEST PROGRAM DESCRIPTION," PRESENTATION TO EUROPEAN SPACE AGENCY/MBB DEUTCHE AEROSPACE, NASA LeRC, OCTOBER, 1992.

NASA Electrical Power Wiring Program - Tentative Testing Schedule



PROGRAM SCHEDULE



Program Products

- **Final Report: FY95**
  - Operational environments report: Task 1
  - Test report: Task 2
  - Wirng systems technology report: Task 3
  - Conclusions
- **Recommended applications for wiring designs tested**

ESTEC WIRING TEST PROGRAMME MATERIALS RELATED PROPERTIES

M.D. Judd
ESTEC/ESA
Noordwijk, Netherlands

INTRODUCTION

- ELECTRICAL WIRES ARE CONSIDERED AS EEE PARTS AND ARE COVERED WITHIN THE ESA SCC SPECIFICATION SERIES (ESA SCC 3901/XXX)

- SPECIFICATIONS DEFINE THE PRINCIPAL PROPERTIES OF THE WIRES INCLUDING INSULATION/LAY UP, ELECTRICAL PROPERTIES ETC.
  SOME ADDITIONAL SPACE RELATED MATERIALS REQUIREMENTS ALSO INCLUDED SUCH AS OUTGASSING AND SILVER PLATING THICKNESS

- IF A PROJECT HAS ADDITIONAL MATERIALS REQUIREMENTS OVER AND ABOVE THOSE COVERED BY THE RELEVANT SCC SPECIFICATION THEN ADDITIONAL TESTING IS REQUIRED.
  THIS IS ESPECIALLY THE CASE FOR MANNED SPACECRAFT

ADDITIONAL REQUIREMENTS FOR MANNED SPACECRAFT

- THE FOLLOWING ADDITIONAL PROPERTIES, SPECIFIC TO MANNED SPACECRAFT (I.E. COLUMBUS AND HERMES) REQUIRE EVALUATION

1. FLAMMABILITY	TEST METHOD ESA-PSS-01-721 ISSUE 2
2. OFFGASSING	TEST METHOD ESA-PSS-01-729 ISSUE 2
3. ARC TRACKING	TEST METHOD UNDER EVALUATION BY DASA/ERNO IN CONJUNCTION WITH TECHNICAL UNIVERSITY, DARMSTADT. THIS WILL BE DESCRIBED IN DETAIL IN A SEPARATE PRESENTATION
4. THERMAL DECOMPOSITION	TEST METHOD DEFINED BASED ON THAT ORIGINATING FROM CERTSM, FRANCE
5. MICROBIAL SURFACE GROWTH	TEST METHOD DEFINED BASED ON THAT ORIGINATING FROM SINTEF/SI, NORWAY

NOTE: 4. AND 5. ARE TEST METHODS DERIVED IN THE FRAME OF THE COLUMBUS PROJECT

- IN ADDITION, THE EFFECTS OF AGEING ON CERTAIN OF THESE PROPERTIES REQUIRE INVESTIGATION

FLAMMABILITY

- WIRE FLAMMABILITY TESTING IS DEFINED IN TEST 2 OF ESA-PSS-01-721 Iss. 2. THIS TEST METHOD WAS DEVELOPED BY DASA/ERNO (UNDER ESA CONTRACT) AND WAS CHOSEN TO REPLACE THE ELECTRICAL OVERLOAD TEST OF NASA NHB 8060.1B.

- TEST METHOD IS BASED ON AN EXISTING ASTM SPEC. AND HAS THE FOLLOWING CHARACTERISTICS:
  . SINGLE WIRE, INCLINED AT 60 DEG.
  . FLOWING TEST ATMOSPHERE, AIR OR ENRICHED OXYGEN ATMOSPHERE
  . WIRE ELECTRICALLY HEATED TO MAX. RATED OPERATING TEMPERATURE DURING TEST
  . OPEN FLAME IGNITION (PROPANE/AIR MIXTURE SUPPLIED FROM OUTSIDE OF THE TEST CHAMBER)
  . ACCEPTANCE CRITERIA BASED ON BURN TIME AND BURN LENGTH.

- TEST HAS BEEN SHOWN TO GIVE VERY REPRODUCIBLE RESULTS IN BOTH REPLICATE TESTS ON THE SAME EQUIPMENT AND ON TESTS PERFORMED ON DIFFERENT TEST SET UPS.

- TEST METHOD PRESENTLY UNDER EVALUATION BY BRITISH STANDARDS INSTITUTE FOR POSSIBLE ADOPTION WITHIN THEIR WIRE TESTING SPECIFICATION.

ARC TRACKING

- ARC TRACKING IS A CONTENTIOUS SUBJECT AND MANY WOULD ARGUE THAT BY GOOD DESIGN PRACTICES AND CONTROL THE PROBLEM CAN BE ELIMINATED.

- MANY TEST METHODS EXIST BUT THE ONLY NATIONAL STANDARDS ARE THOSE DEFINED IN BSG 420 TEST 42 (WET METHOD) AND TEST 43 (DRY METHOD). A DRAFT ASTM SPEC. D3032 IS ALSO AVAILABLE BASED ON THESE TWO TESTS.

- A SURVEY OF EXISTING TEST METHODS, PERFORMED BY DASA/ERNO AND THE TECHNICAL UNIVERSITY OF DARMSTADT, SHOWED THAT NO METHOD WAS AVAILABLE WHICH COULD ADEQUATELY BE USED TO EVALUATE SPACECRAFT MATERIALS. IN PARTICULAR A METHOD WAS REQUIRED WHICH COULD BE USED IN AIR, VACUUM AND ENRICHED OXYGEN ATMOSPHERES AND COULD UTILISE THE DC VOLTAGES COMMONLY USED IN SPACECRAFT POWER SYSTEMS.

- A NEW TEST HAS THEREFORE BEEN DEVELOPED FOR THE TESTING OF SPACECRAFT MATERIALS. THIS WILL BE MORE FULLY DESCRIBED IN A SEPARATE PRESENTATION.

- FUTURE WORK:

  . WORK IN CONTINUING ON INVESTIGATING THE ARC TRACKING BEHAVIOUR OF DIFFERENT WIRE GAUGE SIZES (AWG6, 8, 12, 16) AND USING DIFFERENT VOLTAGE (IN THE RANGE OF 28-270V DC)

  . SOME PRELIMINARY STUDIES WILL BE PERFORMED ON EVALUATING THE EFFECTS OF HUMIDITY OF THE TEST ATMOSPHERE AND OF PREHEATING THE WIRE UNDER TEST.

  . AN EXPERIMENT TO STUDY ARC TRACKING IN A MICROGRAVITY ENVIRONMENT WILL BE CONSTRUCTED STARTING EARLY NEXT YEAR WITH THE AIM OF FLYING ON A PARABOLIC FLIGHT AT THE END OF 1995.

THERMAL DECOMPOSITION

- THERE ARE CLASSICALLY TWO MODES OF TESTING WHEN LOOKING AT THE COMBUSTION PRODUCTS FORMED ON DECOMPOSITION OF MATERIALS. THESE ARE FLAMING AND NON FLAMING COMBUSTION. THE METHOD CHOSEN WILL BE DEPENDENT ON THE FIRE SCENARIO ENVISAGED OBVIOUSLY THE PRODUCTS FORMED ON DECOMPOSITION ARE MARKEDLY DIFFERENT AND THUS IT IS ESSENTIAL THAT THE BASELINE FOR TESTING IS CLEARLY DEFINED PRIOR TO THE START OF ANY COSTLY TEST PROGRAMME.
- ONE APPROACH IS TO TRY, WITH THE BEST MEANS AVAILABLE, TO ENSURE THAT YOUR WIRE INSULATION IS NOT FLAMMABLE AND THUS CANNOT ACT AS A SOURCE OF IGNITION ASSUMING SUITABLE CIRCUIT PROTECTION IS ALSO INCLUDED IN THE DESIGN. IF THIS IS THE CASE THEN IT IS NOT NECESSARY TO LOOK AT MATERIALS IN A FLAMING MODE BUT CAN BE LIMITED TO LOWER TEMPERATURES AT WHICH SMOULDERING MAY OCCUR. IN THE CASE OF THE COLUMBUS PROGRAMME WHERE ALL MATERIALS ARE SUBJECTED TO VERY STRINGENT FLAMMABILITY TESTS, SUCH AN APPROACH HAS BEEN ADOPTED.
- THERE ARE MANY TESTS AVAILABLE FOR STUDYING THE DECOMPOSITION OF MATERIALS AND ASSESSING THE TOXICITY OF THE DEGRADATION PRODUCTS. MOST INVOLVE PLACING THE MATERIAL FOR A DEFINED TIME AT A DEFINED TEMPERATURE AND ANALYSING THE DECOMPOSITION PRODUCTS FORMED (BY GC/MS, GC/FTIR OR COLORIMETRIC TUBES ETC.)

THERMAL DECOMPOSITION (2)

- ONE METHOD, STUDIED VIA THE COLUMBUS PROJECT, IS THAT DEVELOPED BY CERTSM, TOULON, FRANCE FOR LOOKING AT MATERIALS USED IN SUBMARINE CONSTRUCTION. THE METHOD IS BASED ON FRENCH STANDARD NFC 20454 AND INVOLVES HEATING THE MATERIAL AT 800 DEG. C FOR 20 MINUTES IN A FLOWING ATMOSPHERE. SAMPLES OF THE ATMOSPHERE ARE REMOVED AND ANALYSED BY GC/MS OR GC/FTIR. STATISTICAL ANALYSIS ON 50 MATERIALS HAS SHOWN THAT IT IS ONLY NECESSARY TO LOOK FOR 10 COMPOUNDS ("KEY COMPOUNDS") TO OBTAIN SUFFICIENT PRECISION (LESS THAN 5% ERROR) IN CLASSIFYING MATERIALS IN TERMS OF THEIR TOXICITY.
- FOR COLUMBUS, FOR THE REASON MENTIONED EARLIER, A SERIES OF TESTS WILL BE PERFORMED USING THIS METHOD BUT AT LOWER TEMPERATURES, NAMELY 500C AND 200C. THIS WORK SHOULD START EARLY NEXT YEAR.
- IN ADDITION SOME PRELIMINARY STUDIES HAVE BEEN PERFORMED IN ESTEC USING THE CONE CALORIMETER. THIS WORK IS, HOWEVER, AT A VERY EARLY STAGE.

MICROBIAL SURFACE GROWTH

- TEST METHOD BASED ON REPORT 881018 FROM SINTEF/SI (SENTER FOR INDUSTRIFORSKNING, NORWAY) ENTITLED "TEST PROCEDURES AND SPECIFICATIONS FOR ASSESSING THE SUSCEPTIBILITY OR RESISTIVITY TO MICROBIOLOGICAL SURFACE GROWTH OF MATERIALS TO BE USED IN SPACE HABITATS"

- REPORT DEFINES THREE TEST METHODS

  A. SCREENING TEST FOR BACTERIAL GROWTH

  B. SCREENING TEST FOR FUNGAL GROWTH

  C. LONG DURATION TEST

- IT IS PROPOSED TO PERFORM TESTS A. AND B. ON A SERIES OF WIRE SAMPLES STARTING EARLY 94.

AGEING

- AGEING IS A COMPLICATED PROCESS AND THE MECHANISMS BY WHICH THIS OCCURS VARY FROM MATERIAL TO MATERIAL. METHODS ARE AVAILABLE TO ARTIFICIALLY AGE MATERIALS. THESE FREQUENTLY INVOLVE THE USE OF ELEVATED TEMPERATURE BUT CARE HAS TO BE TAKEN TO ENSURE THAT THE TEMPERATURES USED DO NOT INDUCE ADDITIONAL CHANGES WITHIN THE MATERIAL ON TOP OF THOSE DUE TO AGEING.

- SINCE SOME OF THE PROPERTIES STUDIED BY THE TESTS REFERRED TO EARLIER MAY WELL CHANGE DUE TO AGEING IT IS INTENDED TO SUBJECT SEVERAL WIRE SAMPLES TO AN ARTIFICIAL AGEING PROCESS (METHOD PRESENTLY TBD, BUT UNDER PREPARATION BY DASA/ERNO) AND THEN TO REPEAT

  A. FLAMMABILITY TEST

  B. ARC TRACKING TEST

THIS WORK SHOULD BE COMPLETED BY END 1994.

ROBUST 300 °C WIRE INSULATION SYSTEM

John G. Nairus
U.S. Air Force
Wright Patterson Air Force Base, Ohio

OBJECTIVE

IDENTIFY, DEVELOP AND DEMONSTRATE AN OPTIMUM WIRE INSULATION SYSTEM CAPABLE OF CONTINUOUS OPERATION AT 300°C WHICH POSSESSES A COMBINATION OF SUPERIOR ELECTRICAL (AC OR DC), MECHANICAL, AND PHYSICAL PROPERTIES OVER KAPTON^{R} DERIVED INSULATIONS DESCRIBED IN MIL-W-81381 AND THOSE HYBRID CONSTRUCTIONS IDENTIFIED IN AIR FORCE CONTRACT F33615-89-C-5606 COMMONLY KNOWN AS TKT CONSTRUCTIONS.

APPROACH

TASK I: FILM/ADHESIVE CANDIDATE SCREENING

↓

TASK II: DETAILED FILM/ADHESIVE SYSTEM TESTING

↓

TASK III: INITIAL WIRE INSULATION AND TESTING

↓

TASK IV: DETAILED WIRE TESTING

FILM/ADHESIVE CANDIDATE SCREENING

DESIGN OF EXPERIMENTS (DOX) APPROACH FOR CANDIDATE SELECTION

- MINIMUM OF SIX CANDIDATES
- CAST FILM CANDIDATES
- DETERMINE KEY ELECTRICAL AND MECHANICAL PROPERTIES

TASK I PROPERTIES

TABLE I: PROPOSED TASK I SCREENING PROPERTIES TO BE DETERMINED

Property to be Determined	Method of Determination
Electrical	
Dielectric Constant at 400 Hz and 1000 Hz at RT, 280°C, and 300°C	ASTM D-150
Dissipation Factor at conditions stated above	ASTM D-150
Breakdown Voltage (AC at 60 Hz and DC) at RT, 280°C, and 300°C	ASTM D-149
Arc Tracking at RT	ASTM-495-84
Mechanical	
Tensile strength, elongation to break, and modulus at RT, 280°C, and 300°C	ASTM D-882-64T
Lap shear tensile strengths at RT, 280°C, and 300°C	Modification to above tensile method
Dynamic work loss (tan delta)	Rheometrics dynamic analyzer from < -100°C to + 500°C

DETAILED FILM/ADHESIVE SYSTEM TESTING

FOUR TASK I CANDIDATES

BOND SAMPLES (PFPI / AFR700)

SAMPLE AGING (BONDED, UNBONDED, CONTROL)
- FLOWING AIR
- HIGH HUMIDITY
- AIRCRAFT FLUID(S)

SAMPLE TESTING → TWO CANDIDATES

INITIAL WIRE INSULATION AND TEST

TWO TASK II CANDIDATES

CAST/CUT FILMS AND ADHESIVES

INITIAL WIRE WRAP

INSULATED WIRE TESTS → ONE CANDIDATE

ie:
- ABRASION
- FLEX LIFE
- DRY ARC TRACK

MIL-W-81381
KAPTON DERIVED CONTROL

DETAILED WIRE TESTING

ONE TASK III CANDIDATE → FINAL WIRE WRAP

↓

MIL-W-81381
KAPTON DERIVED CONTROL → DETAILED WIRE TEST (BEFORE, DURING, AFTER AGING)
(TESTS BEYOND TASK III)
ie: - DYNAMIC CUT THROUGH
- WET ARC TRACK

↓

LIFE CYCLE ANALYSIS

NASA ENVIRONMENTS

PRESSURIZED MODULE

- PROPOSED MATERIAL HAS SUCCESSFULLY COMPLETED LONG TERM AGING TESTS IN OXYGEN IN PREVIOUS AF PROGRAM

TRANS-ATMOSPHERIC VEHICLE

- PROPOSED MATERIAL HAS SUCCESSFULLY COMPLETED VACUUM, UV AGING, AND TEMPERATURE TESTS IN PREVIOUS AF PROGRAM
- HAVE NOT DONE COMBINED TESTS (ie: PLASMA EFFECTS)

LUNAR AND MARTIAN

- POLYIMIDES KNOWN FOR RADIATION RESISTANCE

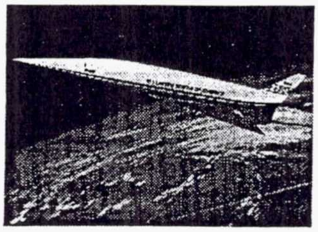
LEO/GEO

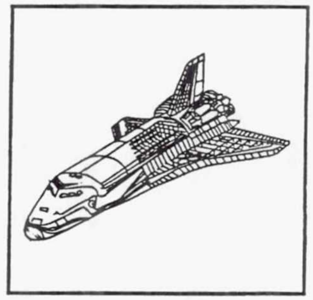
- WL HAS SPACE TESTED FILM SAMPLES WHICH ARE BEING DELIVERED FOR TEST AND ANALYSIS

ADDITIONAL NOTES

- PROPOSED SYSTEM SHOULD NOT BE AFFECTED BY GRAVITY
- EXISTING POLYIMIDE TECHNOLOGY ALREADY EXCEEDS LIFETIME REQUIREMENTS
- 160 VDC SHOULD BE FEASIBLE BASED ON BDV TESTS

NASA APPROACH



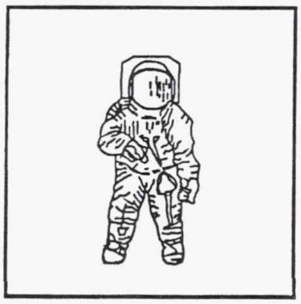


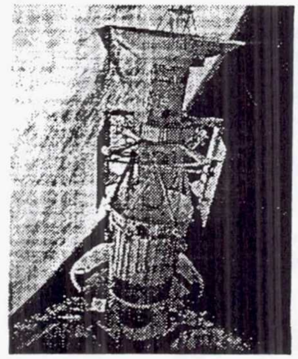
TASK I:
NASA OPERATIONAL ENVIRONMENTS

TASK II:
INSULATION TEST AND ANALYSIS

TASK III:
WIRING SYSTEMS TECHNOLOGY

TASK IV:
MANAGEMENT PLANNING





CONCLUSIONS

OPPORTUNITIES EXIST FOR COOPERATIVE NASA/AIR FORCE EFFORTS

- INSULATION CONTRACT IS FLEXIBLE BUT ALREADY ADDRESSES NASA CONCERNS/ISSUES

- GENERIC AIR FORCE ELECTRICAL LOAD MANAGEMENT TECHNOLOGY IS APPLICABLE

NASA

AFMC
AIR FORCE MATERIEL COMMAND

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SESSION II

WIRING APPLICATIONS AND STANDARDS

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NASA WIRING PROGRAM—SURVEY OF NASA EXPERIENCES IN WIRING SYSTEM SAFETY

Mark W. Stavnes
Sverdrup Technology, Inc.
Lewis Research Center Group
Brook Park, Ohio

NASA Wiring Program

Wiring System Technology

OBJECTIVE

To address safety and reliability issues of complete wiring systems.

PLANS

- **Determine Wiring System Design Factors**
- **Investigate Circuit Protection Technologies**
- **Address Manufacturing and Maintenance Procedures**

NASA Wiring Program

Wiring System Failure Survey

- Apollo 13 Review Board.
- Space Shuttle Program Office and Inspection Teams (NASA Johnson, NASA Kennedy, NASA Marshall, and contractors).
- NASA Payload Inspections (NASA Marshall).

PURPOSE

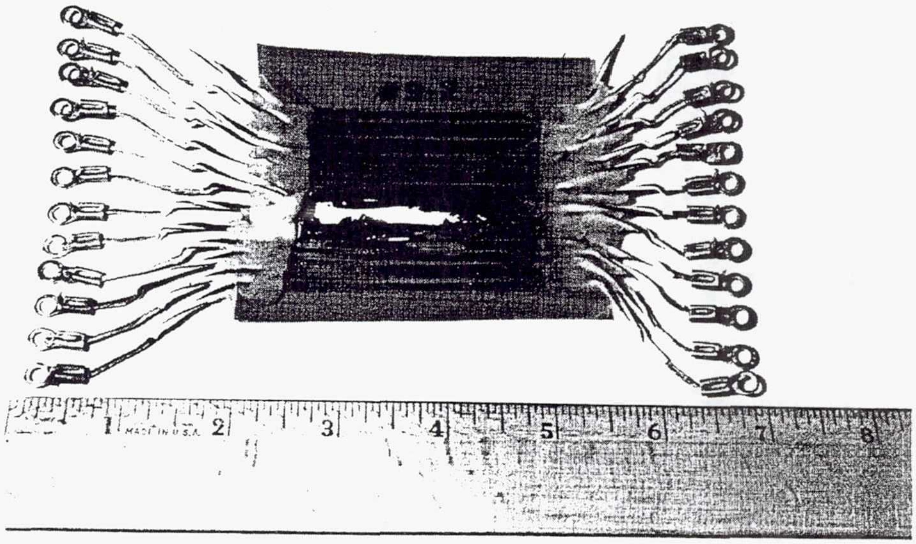
Form a comprehensive view of wiring safety, not only including the insulation, but also taking into account the wiring system factors.

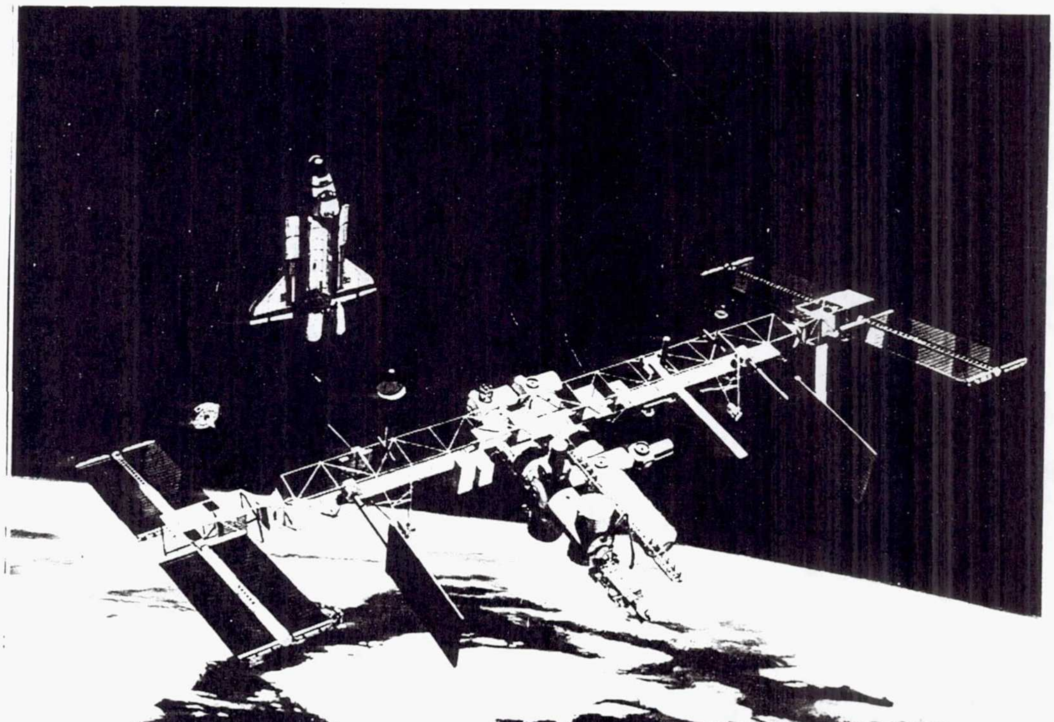
JUSTIFICATION

For failures such as arc tracking and others to happen, insulation degradation of some degree must have occured. The wiring system factors can often lead to degradation.

Overview of Space Missions with Wiring System Failures

Mission	Cause	Result
Gemini 8	Electrical Wiring Short	Shortened Mission - Near Loss of Crew
Apollo 204	Damaged Insulation, Electrical Spark, 100% O_2	Fire, 3 Astronauts Lost
Apollo 13	Damaged Insulation/Short Circuit/Flawed Design	Oxygen Tank Explosion, Mission Incomplete
STS - 6	Abrasion of Insulation/Arc Tracking	Wire Insulation Pyrolysis 6 Conductors Melted
STS - 28	Damaged Insulation/Arc Tracking	Teleprinter Cable Insulation Pyrolysis
Magellan	Wrong Connection, Wiring Short	Wiring Insulation Pyrolysis - Ground Processing
Spacelab	Damaged Insulation/Arc Tracking	Wiring Insulation Pyrolysis During Maintenance
Delta 178/GOES-G	Mechanical or Electrochemical Insulation Damage	Loss of Vehicle
ESA - Olympus	Electrical Wiring Short	Loss of Solar Array





Electrical Wiring System Failures

Influenced by a Combination of Factors

Wiring System Design
Circuit Protection Technology
Manufacturing/Maintenance Procedures
Insulation Construction/Material

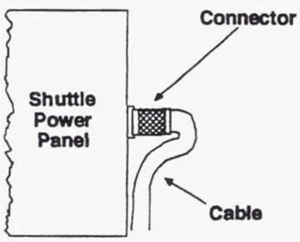
Electrical Wiring System Failures

EXAMPLES

Wiring System Design

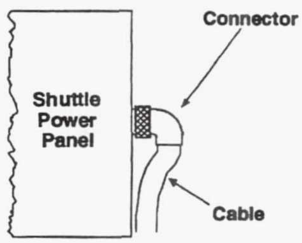
Space Shuttle (STS-28)

Original Teleprinter Cable



- Wire makes 180˚ bend.
- Repeated bending damaged insulation.

Redesigned Teleprinter Cable

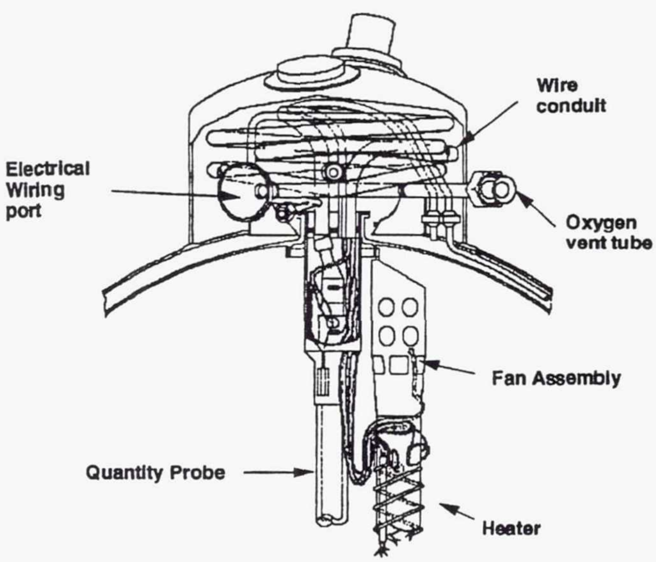


- 90˚ Strain relief added.
- More flexible insulation used.

Wiring System Design

Command and Service Module (Apollo 13)

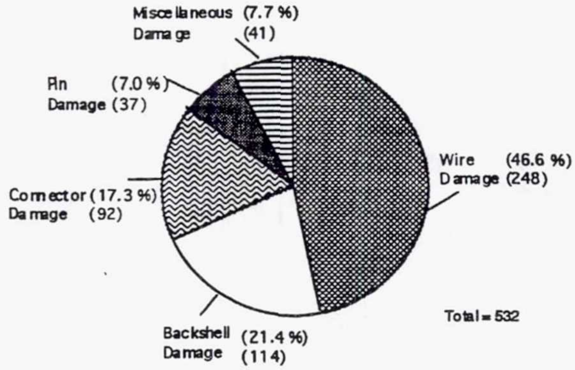
Oxygen Tank Failure



- **Tanks contained ignition sources, combustible materials, and oxygen.**
- **Electrical wiring conduit constrictive.**
- **Wiring in close proximity to heaters.**
- **Pressure against sharp edges could lead to "Cold Flow".**
- **Failure modes were not detectable by normal post assembly testing.**

Maintenance Procedures

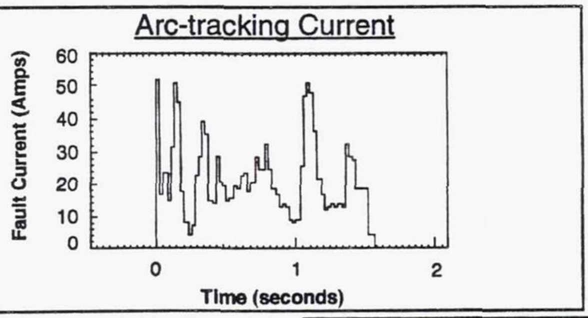
Space Shuttle Orbiters



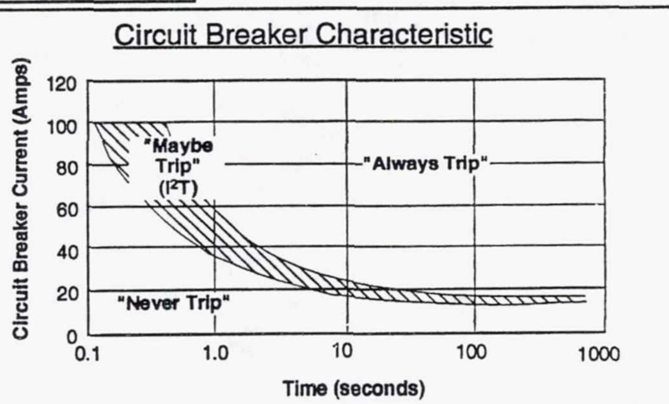
- During 1984 and 1985 there were 532 cable and connector problems reported.
- Problems resulted due to maintenance procedures.

Circuit Protection Technology

Space Shuttle (STS-28)



- Circuit breakers based on the thermal energy in the fault, may be ineffective in detecting arc-tracking.



- NASA Johnson Space Center Test Program - arc propagation limited to lengths of less than 1" up to 6".
- New technologies may improve detection.

Electrical Wiring System Improvements

EXAMPLES

Wiring System Design Improvements

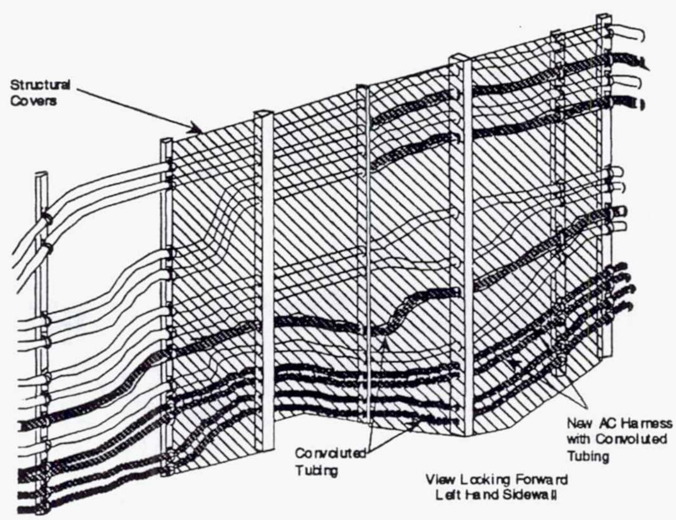
- Awareness of designers to fault mechanisms.
- Specify new insulation constructions and materials for use in NASA spacecraft.

Manufacturing/Maintenance Procedure Improvements

- Improved training of personnel in "Wiring Awareness" techniques
- Routing/Protecting of wiring to avoid physical damage
- Improved quality control, including non-intrusive inspections
- Application of methods such as dynamic system engineering and total quality management.

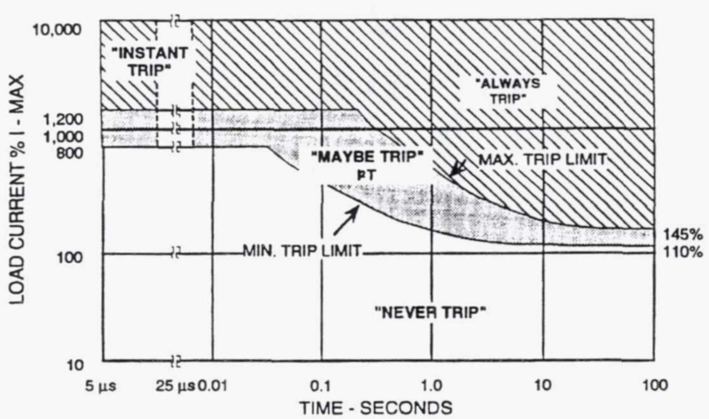
Wiring Protection Measures

Space Shuttle Orbiters



Advanced Protection Technology

"Instantaneous Trip" Circuit Breakers

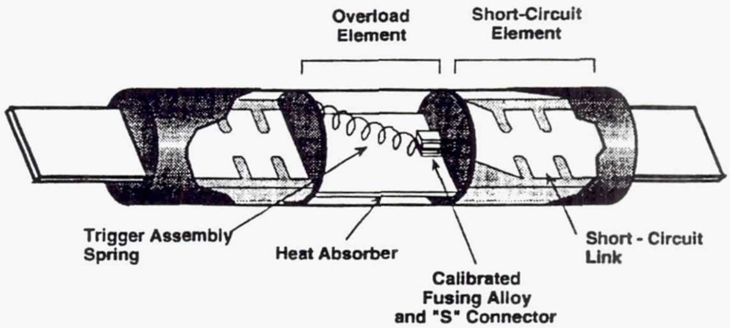


- Commercially Available Solid State Power Controllers (SSPC)
- Air Force 270 VDC SSPC Program

Advanced Protection Technology

"Smart" Fuses

Dual-element Time-delay Fuse



- Provide protection against low-level overload current or a short circuit current.

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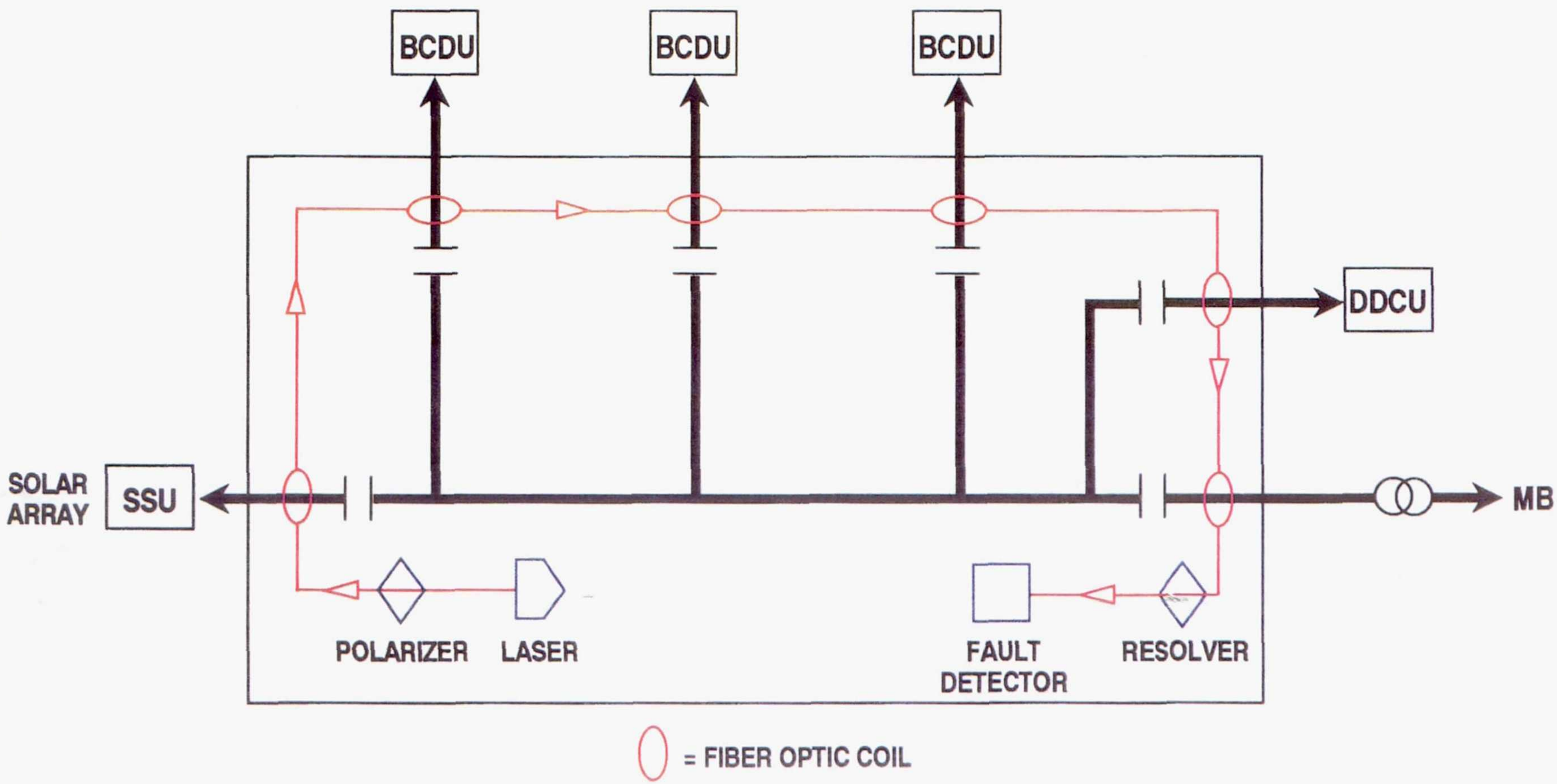
Lewis Research Center

DIFFERENTIAL PROTECTION OF DCSU USING FIBER OPTIC CURRENT SENSING

POWER TECHNOLOGY DIVISION



FAULT SIGNAL $\propto \underbrace{I_{SSU} + I_{BCDU1} + I_{BCDU2} + I_{BCDU3} + I_{DDCU} + I_{MB}}_{\emptyset} + I_{FAULT}$

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Advanced Protection Technology

"Intelligent" Fault Detection Methods

- Incipient fault detection via "footprint" or "signature"
- Knowledge based expert systems
- Neural network methods
- Fuzzy logic methods

Summary

- The wiring system is an important consideration in designing a spacecraft power system.
- Arc-tracking has recently been identified as a failure mode which may not be completely eliminated through the use of new wiring constructions/materials
- The total wiring system including insulation, system design, handling procedures, and circuit protection need to be considered further.

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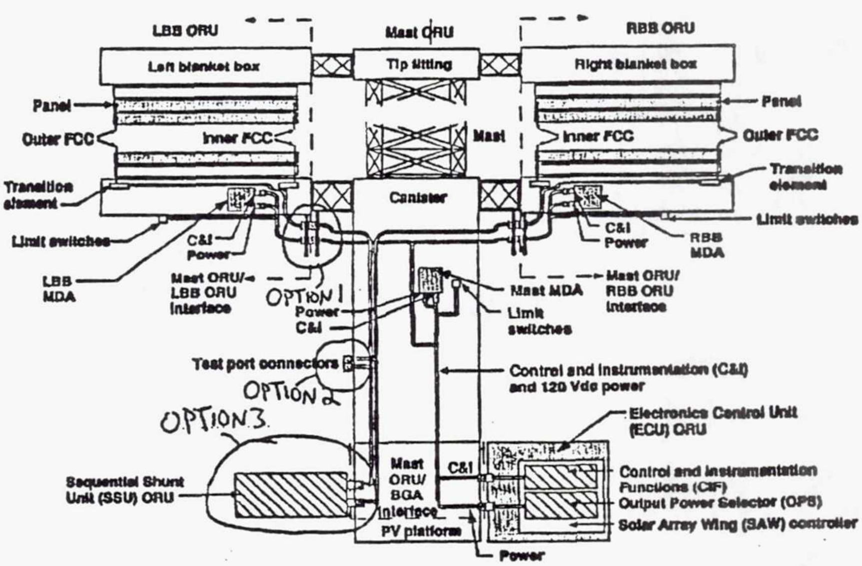
SELECTION OF THE SPACE STATION FREEDOM (SSF) FLAT COLLECTOR CIRCUIT (FCC) INSULATION MATERIAL

Dawn Emerson
NASA Lewis Research Center
Cleveland, Ohio

FUNCTION OF FCC:

A FLEXIBLE CABLE WHICH PROVIDES MULTIPLE ELECTRICAL PATHS FOR THE DISTRIBUTION OF ELECTRICAL POWER FROM CIRCUIT COMPONENTS ON THE SSF SOLAR ARRAY.

Array Power Deadfacing Option Locations



REQUIREMENTS OF THE FCC WHICH AFFECT THE SELECTION OF THE INSULATION MATERIAL

THE FCC SHALL PERFORM AS SPECIFIED AFTER EXPOSURE TO THE FOLLOWING ENVIRONMENTS:

- ATOMIC OXYGEN EXPOSURE - TOTAL FLUENCE 5.4 x 10^{22} AO/CM^2. (15 YEARS OF EXPOSURE)
- ULTRAVIOLET RADIATION EXPOSURE - 10 SUN YEARS (2/3 OF ILLUMINATED ORBITAL TIME OVER 15 YEARS).
- THERMAL CYCLES - 87,000 THERMAL CYCLES BETWEEN $\pm$ 100°C.
- STORAGE LIFE - 5 YEARS SHELF LIFT UNDER FOLLOWING ENVIRONMENT:

  TEMPERATURE = +10, +40°C
  RELATIVE HUMIDITY - 20 TO 60%
  PRESSURE - 650 TO 810 TORR

OTHER REQUIREMENTS:

- THE FCC SHALL NOT ADHERE TO ITSELF. (BLOCKING)
- THE SURFACE OF THE FCC SHALL HAVE A SOLAR ABSORPTIVITY $\leq$ .45 BOL.
- THE SURFACE OF THE FCC SHALL HAVE AN INFRARED EMISSIVITY $\geq$ .85 AT BOL.

DATA TO SUPPORT THE SELECTION OF THE FCC INSULATION MATERIAL WAS OBTAINED THRU DEVELOPMENT WORK ASSOCIATED WITH THE SA COVERLAY.

- o THE SAME MATERIAL IS USED FOR THE FCC INSULATION AND THE SA COVERLAY.

- o THE DEVELOPMENT WORK TO BE PRESENTED WAS DONE ON THE SOLAR ARRAY COVERLAY MATERIAL. THE FINDINGS ARE APPLICABLE TO THE FCC APPLICATION.

  - COVERLAY IS THE STRUCTURAL LAYER OF THE SOLAR ARRAY TO WHICH THE SOLAR CELLS ARE BONDED.

  - COVERLAY ALSO FUNCTIONS AS THE DIELECTRIC BETWEEN THE INTERCONNECTING CIRCUITRY ON THE SA AND THE LEO ENVIRONMENT.

DEVELOPMENT HISTORY

INITIAL SELECTION (1989):
SiOx COATED 1 MIL THICK KAPTON H.

- INITIAL DESIGN WAS BASED ON MILSTAR AND SAFE FLEXIBLE SOLAR ARRAY DESIGNS AND MATERIAL DEVELOPMENT WORK PERFORMED BY LMSC UNDER LeRC CONTRACT.

TESTS PERFORMED:
SHORT EXPOSURE TO RF GENERATED OXYGEN PLASMA (1 WK).

TEST RESULTS:
SiOx COATED KAPTON EXHIBITED A DECREASE IN THE AO INDUCED MASS LOSS RATE RELATIVE TO BARE KAPTON (REDUCTION IN MASS LOSS RATE UP TO 100x).

TEST LIMITATIONS:
LONG DURATION TESTS NECESSARY FOR SSF APPLICATIONS WERE OUTSIDE THE SCOPE OF THE INITIAL MATERIAL DEVELOPMENT PROGRAM.

INITIAL SELECTION (1989)

FURTHER TESTING FOR SSF APPLICATIONS

TESTS PERFORMED:
SIMULATED LONG DURATION AO STABILITY TESTS (SIMULATED 15 YR EXPOSURE).

TEST RESULTS:

- o SiOx COATING ITSELF DISPLAYED SUPERIOR STABILITY AGAINST AO ATTACK.
- o ANY BREAKS INITIALLY PRESENT IN COATING RESULTED IN EROSION OF THE UNDERLAYING MATERIAL.
- o TENSILE STRENGTH OF THE COVERLAY DECREASES RAPIDLY DUE TO THE LOW TEAR PROPAGATION STRENGTH OF KAPTON.

CONCLUSION:

- o COVERLAY APPLICATION REQUIRED A MATERIAL WITH GREATER MECHANICAL STRENGTH RETENTION TO MEET SA LOAD REQUIREMENTS.
- o EROSION OF THE KAPTON INSULATION MATERIAL IN THE FCC APPLICATION MAY INCREASE THE PROBABILITY OF SHORT CIRCUIT

MODIFIED DESIGN

E-GLASS TESTING:

ENVIRONMENT	DURATION/EXPOSURE	RESULTS
HUMIDITY	30 DAY AT 90% RH 85°C	EXHIBITED ADEQUATE PROPERTIES FOR LONG TERM STORAGE.
SIMULATED ATOMIC OXYGEN ON UNSIZED E-GLASS	EFFECTIVE FLUENCE 1.5×10^{22} AO/CM^2 30% EXPECTED SSF EXPOSURE	NO CHANGE IN MATERIAL STRENGTH
SIMULATED AO ON SIZED E-GLASS (S-938* SIZING)	$.07 \times 10^{22}$ AO/CM^2 1% EXPECTED SSF EXPOSURE	30% LOSS IN TENSILE STRENGTH/ STRENGTH OF SIZED CLOTH REMAINED ABOVE STRENGTH OF UNSIZED CLOTH

*SILANE SIZING (S-938) INCREASES THE TENSILE STRENGTH AND IMPROVES THE ADHESION OF FIBERS TO SILICONE.

MODIFIED DESIGN (1990) BASELINE:

1300Å SiOx COATING
1 MIL KAPTON H
1300Å SiOx COATING
1.5 MIL THICK STYLE 106 E-GLASS IMPREGNATED WITH NUSIL TECHNOLOGY CV1-2502 SILICONE
1 MIL BARE KAPTON HN

ADVANTAGES OF NEW DESIGN:

- FIBERGLASS PROVIDES STRENGTH RETENTION (ASSUMES LOAD CARRYING ROLE).
- 2 LAYERS OF SiOx COATING PROTECT THE FIBERS IN THE SILICONE MATRIX.
- EVEN AFTER THE FIBERS IN THE SILICONE MATRIX ARE EXPOSED, STABILITY OF THE GLASS UNDER AO EXPOSURE WILL AID IN MAINTAINING TEAR RESISTANCE AND STRENGTH.
- OUTER LAYER OF SiOx PREVENTS BLOCKING.

COVERLAY TESTING - ASSUMED END-OF-LIFE CONFIGURATION

EOL CONFIGURATION REPRESENTS WORST-CASE CONDITION AFTER BOTH LAYERS OF KAPTON ARE ERODED AWAY. CONFIGURATION CONSIDERED TO PRODUCE CONSERVATIVE RESULTS.

ENVIRONMENT	DURATION/EXPOSURE	RESULTS
1. AO	EFFECTIVE FLUENCE 2.9×10^{22} AO/CM^2 60% SSF EXPOSURE LEVEL	o* EMBRITTLED REGIONS o LOSS OF TENSILE STRENGTH

*RESULTS WERE NOT CONSIDERED WITH EXPECTED RESULT BASED ON LDEF DATA, WHICH INDICATED SILICONE HAS GOOD RESISTANCE TO AO EMBRITTLEMENT.

UV	8000 EQUIVALENT SUN HRS AT 2 SUNS INTENSITY	INCREASE IN TENSILE STRENGTH FROM 30-40 LB/IN NO CRACKING OBSERVED. SLIGHT DARKENING

ENVIRONMENT	DURATION/EXPOSURE	RESULTS
2. AO (RECENT DATA SEPARATE LOT)	80% SSF EXPOSURE LEVEL	RETENTION OF TENSILE STRENGTH PROPERTIES ON BOTH BOL, EOL SPECIMENS

*THE VARIATION IN TEST VALUES EXHIBITED IN AO TEST 1 COMPARED TO EARLIER DATA AND CURRENT DATA ARE ATTRIBUTED TO EITHER:

- o DEPENDENCE OF TEST CONFIGURATION
- o LOT TO LOT VARIATION

CONCLUSION

THE MOST SIGNIFICANT ENVIRONMENTAL EXPOSURE EFFECTS ARE FROM ATOMIC OXYGEN.

THE MODIFICATION TO THE COVERLAY PROVIDE FOR GREATER ROBUSTNESS TO THE EFFECTS OF LONG LEO EXPOSURE.

EFFECTS ON MODIFIED DESIGN ON FCC

o CHANGES TO THE COVERLAY DRIVEN BY THE NEED TO IMPROVE THE SA STRENGTH RETENTION SERVED TO BENEFIT THE FCC:

1. PROVIDES BETTER PROTECTION AGAINST THE OCCURRENCE OF EXPOSED COPPER CONDUCTOR.

   (INITIAL DESIGN - IMPERFECTIONS IN SiOx COATING RESULTED IN EROSION OF KAPTON AND SUBSEQUENT TEARING, LEADING TO EXPOSED CONDUCTOR.)

*2. A. TESTS INDICATE THE MODIFIED DESIGN IS MORE RESILIENT TO ARC TRACKING INITIATION.

   B. MODIFIED DESIGN ELIMINATED FLASH OVER.

* NASA CONTRACTOR REPORT 191106, THOMAS J. STUEBER

ARC TRACKING TESTS PERFORMED ON FCC

CHARACTERISTIC OF KAPTON:

KAPTON POLYMIDE WIRING INSULATION IS VULNERABLE TO PYROLIZATION (CHARRING), ARC TRACKING AND FLASHOVER WHEN MOMENTARY SHORT CIRCUIT ARCS APPEAR.

- o ARC TRACKING OCCURS WHEN THE SHORT CIRCUIT ARC PROPAGATES DOWN THE WIRE THRU CONTINUED PYROLIZATION.

- o FLASHOVER OCCURS WHEN AN ARC INVOLVING ONE PAIR OF WIRES CHARS ADJOINING WIRING RESULTING IN MULTIPLE FAILURES.

ARC TRACKING TEST WERE CONDUCTED BY:

1. GENERATING A DEFECT LOCATED BETWEEN ONE OF THE SUPPLY LINES AND ITS CORRESPONDING RETURN LINE WHICH EXPOSES A SMALL AREA OF THE COPPER RETURN LINE.

2. SAMPLES WERE PREPYROLIZED BY CREATING A MOMENTARY SHORT CIRCUIT ARC. POWER WAS THEN TURNED OFF.

3. TEST WAS CONDUCTED TO DETERMINE THE MINIMUM OPEN CIRCUIT VOLTAGE AND SHORT CIRCUIT CURRENT NECESSARY TO RESTART THE ARC TRACKING EVENT.

FLASHOVER TESTS WERE CONDUCTED ON 3 SIDE-BY-SIDE ENERGIZED CHANNELS.

1. FLASHOVER TEST WAS CONDUCTED BY PROMOTING THE ARC TRACKING EVENT BY SHORTING THE MIDDLE CHANNEL WITH ADJOINING CHANNELS ENERGIZED.

ARC TRACKING TEST RESULTS

ARC TRACKING:

A MOMENTARY SHORT CIRCUIT DID INITIATE KAPTON PYROLYSIS AT POWER LEVELS BELOW SSF OPERATING LEVELS. HOWEVER, NEW DESIGN WAS MORE RESILIENT TO ARC TRACKING INITIATION THAN PREVIOUS DESIGN.

PREVIOUS DESIGN:

ARC TRACKING WAS INITIATED AT THE EPOCH OF THE FIRST MOMENTARY SHORT CIRCUIT.

NEW DESIGN:

TYPICALLY SEVERAL MOMENTARY SHORT CIRCUITS WERE NEEDED TO PYROLIZE THE POLYIMIDE ENOUGH TO INITIATE ARC TRACKING.

FLASHOVER:

THE FLASHOVER EVENT OBSERVED IN EARLIER DESIGNS DID NOT OCCUR WITH THE MODIFIED DESIGN

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NASA PARTS PROGRAM OFFICE RESPONSIBILITIES

Patrick L. Kilroy
NASA Goddard Space Flight Center
Greenbelt, Maryland

NASA PARTS PROGRAM OFFICE RESPONSIBILITIES

- DESIGNATED AS LEAD CENTER OFFICE FOR ELECTRICAL, ELECTRONIC, AND ELECTROMECHANICAL PARTS STANDARDIZATION
- PROGRAM FUNDING FROM NASA HEADQUARTERS OFFICE OF SAFETY AND MISSION ASSURANCE, CODE Q
- LEAD CENTER RESPONSIBILITIES DEFINED THROUGH A NASA MANAGEMENT INSTRUCTION

NASA PARTS PROJECT OFFICE RESPONSIBILITIES

- NMI 5320.6B REQUIREMENTS:
  - ESTABLISH AND ENSURE COMPLIANCE FOR EEE PARTS TECHNICAL REQUIREMENTS
  - OBTAIN CENTER PARTS USAGE DATA
  - DEVELOP AND SUPPORT THE EEE PARTS INFORMATION MANAGEMENT SYSTEM
  - ESTABLISH GROUNDRULES FOR STANDARD PART SELECTIONS
  - EVALUATE AND COORDINATE GOVERNMENT AND MILITARY SPECIFICATIONS, STANDARDS, AND HANDBOOKS
  - ESTABLISH STANDARD PART QUALIFICATION REQUIREMENTS, PERFORM MANUFACTURER AUDITS AND SURVEYS, LEVERAGE OFF QPL AND QML ACTIVITIES
  - UPDATE AND MAINTAIN STANDARD PART DOCUMENTS (MIL-STD-975, MIL-HDBK-978, ETC...)
  - DEVELOP TEST AND ANALYSIS REQUIREMENTS, PERFORM PRODUCT EVALUATIONS, DISSEMINATE TEST RESULTS AND REPORTS TO CENTERS, PARTICIPATE IN THE GIDEP PROGRAM

Development Priorities
Identified by the NASA Parts Steering Committee

- GIDEP
  - NASA internal problem rating and status notification system for projects
  - closed-loop system
  - remote notification of impacts to contractors, PI's
- MIL-STD-975
  - complete version with notes, etc.
  - grandfathered versions
  - part selection by attributes
  - nomination of parts; status of candidate parts
- NASA Advisories
  - link to project problem reporting system
- Project Parts Lists
  - enhanced reports
  - direct capture from CAD applications
- Derating Criteria
  - derating calculation
- Manufacturer Surveys/Audits
- Radiation Data
- Parts Library — specification information, selection of parts by parameters

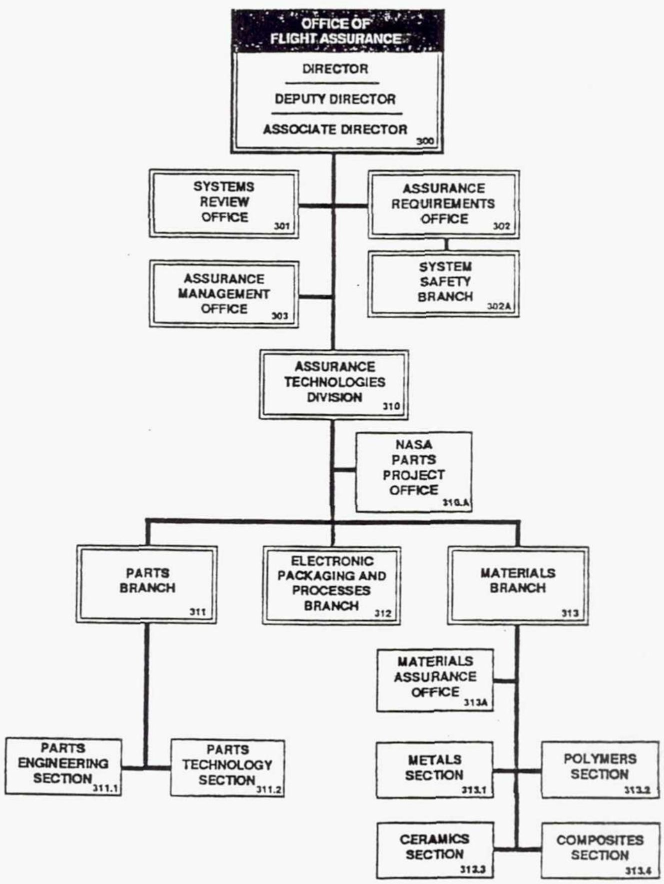
Development Priorities
Identified by the NASA Parts Steering Committee
(continued)

- Parts Selection Lists
- NASA In-House Parts Inventory
- NSPAR's
- Part Specifications
- Reliability Data
- MIL-HDBK-978
- FA's, DPA's, & Evaluations — input function for NASA centers
- Additional reporting capabilities (all functions and applications)
- Functions to download and export data to PC client
- Contractor node implementations
- Technical Documents
- Technical News

Candidate Functions for EPIMS baseline

- GIDEP FEDI and NASA Advisories
- CAGE Directory
- FSC Directory
- User Directory
- Project Parts Lists
- Alert/Advisory Impact Cross-Reference
- MIL-STD-975
- Parts Lists Comparison
- NSPAR's
- Manufacturer Surveys/Audits
- Parts News and Technical Document Archives
- FA/DPA/Evaluation Reports

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER



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NASA PARTS PROJECT OFFICE—BASIC GOALS

Jeannette Plante
Paramax Systems Corporation
A Unisys Company
Lanham, Maryland

BASIC GOALS

1. Determine Standard Parts
2. Route Information Through the Standards and Users Communities
3. Encourage Standardization

A Standard Part Per MIL-STD-975

1. Application Need
2. Technological Maturity
3. Availability of Manufacturers
4. Test or Usage History
5. Characterization Data
6. Evaluation Tests
7. Specification
8. Qualification

Standard Wire in MIL–STD–975

MIL–W–22759	Fluoropolymer	
MIL–W–81381	Polyimide	Removed 1993
MIL–W–16878	Fluoropolymer (non–QPL)	Removed 1993
MIL–C–17	RF Cable	
MIL–C–27500	Cable	

What Is Space Grade? or

What Is Grade 1 and Grade 2?

– Outgassing	– Flammability
– Toxicity	– Odor
– Atomic Oxygen	– Toxicity
– Arc Tracking	– Cold Flow

Center Specific and Application Specific

Conduit and Catalyst for Information Transfer

SAE		NASA Interconnection Standardization Working Group
EIA		Space Parts News
NEMA		
DESC/DISC/ Army Lakehurst	NPPO	NASA Advisories
NAWC		NAS Database
ESA		NASA Parts Steering Committee
NASA		

I S W G

NASA Interconnection Standardization Working Group

NASA	Performance Requirements
OEMs	Procurement, Available Part Quality
Military	Performance Requirments, Qualification, Specifications
Industry	Standards, Manufacturing Techniques, Available Product (planned)
Academia	Test Data

Past and Present Wire Issues

- Red Plague
- Circular Mil Area
- Flammability of ETFE and XL–ETFE
- Degree of Crosslinking
- Conductor Plating
- Arc Tracking – Hybrid Wire
- Derating

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NAVAIR AIRCRAFT WIRING STANDARDIZATION AND QUALIFICATION PROGRAM

Thomas Meiner
Naval Air Warfare Center
Indianapolis, Indiana

WIRING RESPONSIBILITIES

PURPOSE OF PROGRAM

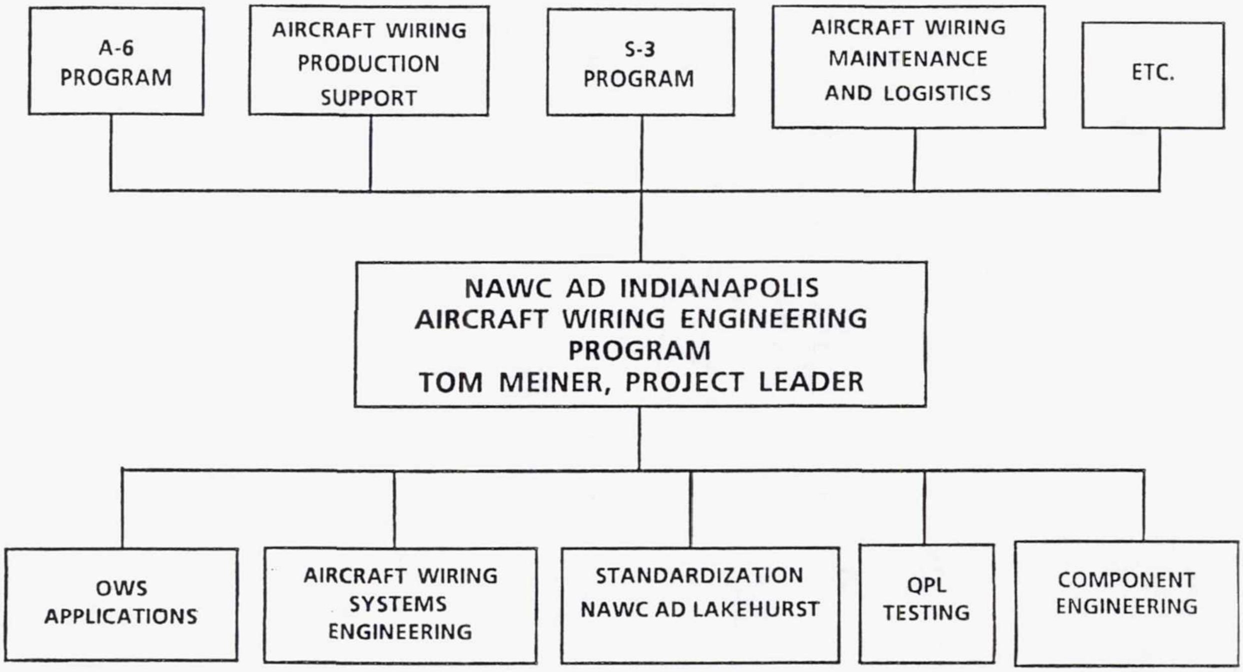
MEASUREMENT OF PROGRAM EFFECTIVENESS

RESULTS

SUMMARY

RESPONSIBILITIES

- DESIGN AND DEVELOP WIRING SYSTEMS
- CONDUCT ENGINEERING INVESTIGATIONS
- WIRING TESTING AND EVALUATION ACTIVITY
  (INCLUDING RECEIVING/INSPECTION)
- QUALIFICATION AGENT/TEST FACILITY
- WIRING MAINTENANCE AND LOGISTICS ENGINEERING
- HARNESS MANUFACTURING



PURPOSE OF PROGRAM

- TO PROVIDE THE MOST COST EFFECTIVE, RELIABLE WIRING COMPONENTS AND SYSTEMS TO OUR CUSTOMERS

WORKLOAD OF PROGRAM
(NUMBERS ARE APPROXIMATE)

- TECHNICAL AGENT FOR 90 SPECIFICATIONS
- QUALIFICATION AGENT FOR 80 OF THESE SPECIFICATIONS
- 300 QUALIFICATION PROJECTS PER YEAR
- 10 - 15 MAJOR COMPONENT EVALUATIONS PER YEAR

EFFECTIVENESS OF PROGRAM

- 50% FAILURE RATE ON INITIAL QUALIFICATION SUBMITTALS
- 30% FAILURE RATE IN RETENTION OF QUALIFICATION PROGRAM
- CORRECTIVE ACTION RESULTS IN OVER 90% APPROVAL RATE
- 80 - 90% OF FAILURES ARE PERFORMANCE RELATED VS. DOCUMENTATION
- 20% REJECTION RATE ON RECEIVING/INSPECTION, 25% OF THESE REJECTIONS ARE QPL PRODUCTS

RESULTS

QUALIFICATION CAN IMPROVE QUALITY BY 75%

QUALIFICATION PROGRAM REDUCES TESTING/COST

HIGHER QUALITY PRODUCTS REDUCE SYSTEM DOWNTIME

MUST BE SUPPLEMENTED BY CUSTOMER'S QUALITY ASSURANCE PROGRAM

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ORGANIZED WIRING SYSTEMS

Thomas Meiner
Naval Air Warfare Center
Indianapolis, Indiana

SUMMARY

- THE WIRING SYSTEM IS THE LINK FOR ALL SYSTEMS, AND MUST BE INCLUDED IN THE QUALITY ASSURANCE PROGRAM.

- WITHOUT QUALIFICATION AND STANDARDIZATION, WIRING MAINTENANCE COSTS WOULD BE EXORBITANT.

- NAVY STUDIES SHOW THAT WIRING (TAKEN COLLECTIVELY) IS CONSISTENTLY ONE OF THE TOP FIVE "BAD ACTOR" SYSTEMS OF EVERY AIRCRAFT TYPE FOR:

  - NON-MISSION CAPABLE (NMC)

  - PARTIAL MISSION CAPABLE (PMC)

  - MAINTENANCE MAN HOURS (M/MHRS)

TRADITIONAL HARNESSING PITFALLS

- EXPENSIVE AND DIFFICULT TO MANUFACTURE,
- NORMALLY INSTALLED PARTIALLY ASSEMBLED,
- DIFFICULT TO MAINTAIN AND MODIFY,
- REQUIRES TWISTED AND SHIELDED COMPONENTS TO CONTROL EMI,
- SIZE AND WEIGHT REDUCTION LIMITED BY MECHANICAL AND ELECTRICAL FACTORS,
- REQUIRES HIGH-COST TRAINING AND PIECE-PARTS LOGISTICS THAT IS OFTEN INEFFECTIVE, AND
- ALL MAINTENANCE IS "O" OR "D"

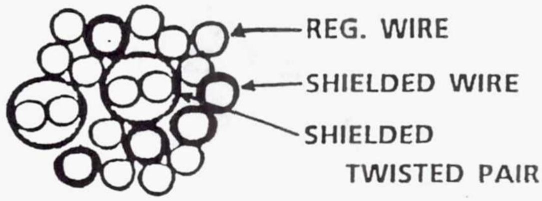
ORGANIZED WIRING: "WIRING WITH FIXED RELATIVE POSITIONING OF CIRCUITS. THIS IS TYPICALLY A RECTANGULAR BUNDLE."

ORGANIZED
WIRING SYSTEMS

ROI I^2S

TYPICAL HARNESS CROSS SECTIONS

CONVENTIONAL HARNESS



ROI HARNESS

OWS IS APPLICABLE TO:

- NEW DESIGN,
- REWORK,
- ECP'S, AND
- ALSO APPLIES TO MISSILES, STORES, PODS, SUSPENSION EQUIPMENT, AND AVIONIC'S SUITES

ADVANTAGES

- WEIGHT SAVINGS
- IMPROVED RELIABILITY
- PREDICTABLE EMI PERFORMANCE
- IMPROVED MAINTAINABILITY
- LIFE CYCLE COST SAVINGS
- ACTIVE WIRING FEATURES

RIBBON HARNESSES REDUCE WEIGHT BY:

- ELIMINATION OF INDIVIDUAL SHIELDS AND JACKETS,
- LESS OUTER BRAID PER UNIT HARNESS LENGTH,
- ELIMINATION OF SHIELD - TERMINATORS AND EMI BACKSHELLS,
- DOWN-GUAGING OF WIRES DUE TO IMPROVED MECHANICAL AND ELECTRICAL CHARACTERISTICS OR RIBBONS, AND
- REPLACING HEAVY COAX WITH STANDARD WIRE IN CERTAIN APPLICATIONS

WIRING SYSTEM WEIGHT REDUCTION TECHNIQUES
DOWNGAUGING VS. SHIELD ELIMINATION
(WEIGHTS USED ARE TYPICAL)

24 GAUGE
SHIELDED WIRE
7.3 LBS/KFT

26 GAUGE
SHIELDED WIRE
6.2 LBS/KFT
15% REDUCTION

24 GA REG WIRE
2.5 LBS/KFT
66% REDUCTION

26 GA REG WIRE
1.8 LBS/KFT
75% REDUCTION

ORGANIZATION METHODOLOGY

- CIRCUITS ARE GROUPED BY AMPERAGE ONTO POWER RIBBONS AND SIGNAL RIBBONS
- CIRCUITS ARE POSITIONED ON RIBBONS TO ELIMINATE DETRIMENTAL CROSSTALK; FOR EXAMPLE,
  - LOW IMPEDANCE GROUPING
  - HIGH IMPEDANCE GROUPING
  - SPIKE CIRCUITS POSITIONING
- HIGH AMPERAGE CIRCUITS MAY BE SEPARATED TO ENHANCE HEAT DISSIPATION; FOR EXAMPLE,
  - "ON/OFF" CIRCUIT SEQUENCING
- RESULTS IN RELIABLE, PREDICTABLE E^3 PERFORMANCE

WIRING INTEGRATION UNITS PERFORM MANY FUNCTIONS:

- CIRCUIT COLLECTION AND REDISTRIBUTION POINTS,
- RIBBONS HARNESS CIRCUIT ORGANIZATION POINTS,
- WIRE GAUGE CHANGE POINTS,
- RIBBON HARNESS/ENDPOINT HARNESS INTERFACE

WIU's CAN INCORPORATE:

- ACTIVE CIRCUITRY (RELAYS, IC'S, FUEL QUANTITY SYSTEM SIMULATORS, ETC.),
- DISCRETE FILTERS,
- DATA BUS COUPLERS/FIBER OPTIC DECODERS,
- BUILT-IN-TEST (BIT) SYSTEMS,
- SYSTEM MONITORING CIRCUITRY, AND
- SELF-HEALING CAPABILITIES

- MODULARITY PROVIDES:
  - SYSTEM GROWTH POTENTIAL AND SIMPLIFIES MODIFICATION
  - ENHANCED REPAIR CAPABILITIES BOTH ON AND OFF AIRCRAFT
  - THE CAPABILITY TO REPLACE DAMAGED/REPAIRED HARNESSES AND WIUs TO BRING WIRING SYSTEM BACK TO "LIKE NEW" CONDITION DURING THE ENTIRE SERVICE LIFE OF THE AIRCRAFT
  - FOR THE FULL APPLICATION OF THE LOGISTICS SUPPORT ANALYSIS (LSA) PROCESS TO WIRING SYSTEMS
  - LIFE CYCLE COST SAVINGS

END POINT HARNESSES:

- ARE SHORT AND SIMPLE
- R&R AT "O" AND REPAIR AT "I"
- EASILY UPGRADED OR REPLACED FOR SYSTEM UPGRADES, AND
- CAN INCORPORATE CERTAIN RIBBON HARNESS FEATURES

NAVAIR DIRECTIVE

13200
Ser AIR-546D4

JUN 28 1991

MEMORANDUM

From: AIR-546
To: AIR-511A
Via: AIR-516

Subj: CHANGE TO SD-24

1. During a meeting among AIR-546, AIR-516, and AIR-411 it was decided to revise pargraph 3.16.5 of SD-24 as follows:

a. 3.16.5 WIRING - The signal and power distribution wiring shall be an organized wiring system such that all circuits are maintained in the same relative position to one another throughout their entire length. The design of the organized wiring system and the selection of its electrical components shall be proposed by the contractor and approved by NAVAIR. Conventional electrical wiring...

2. We all concur with this approach. I am preparing a separate package that will be routed for AIR-05 and AIR-04 endorsement of this change.

3. If there are any questions my point of contact is Mr. David Pielmeier, 692-7125, AIR-546D4

W F Savage

CAPT W. F. SAVAGE
AIR-546
Division Director

Copy to:
AIR-411
AIR-546D4
AIR-516

BENEFITS OF ROI

- WEIGHT SAVINGS THROUGH ORGANIZATION AND ELIMINATION OF INDIVIDUAL SHIELDS AND ASSOCIATED HARDWARE
- LIFE CYCLE COST SAVINGS
- RELIABLE, PREDICTABLE E^3 PERFORMANCE
- UTILIZES EXISTING TOOLS, LITTLE ADDITIONAL TRAINING
- DESIGN FLEXIBILITY TO MEET SYSTEM REQUIREMENTS
- INTERFACES WITH EXISTING AVIONICS

ADVANTAGES OF WOVEN RIBBON ELEMENTS:

ROI RIBBONS:

- ARE NOT RESTRICTED TO "STANDARD" RIBBON WIDTHS,
- CAN INCORPORATE ANY GAUGE SIZE WIRES,
- MAY BE DESIGNED WITH A MIXTURE OF GAUGE SIZES,
- ARE EASILY FABRICATED, AND
- ARE COMPATIBLE WITH EXISTING FLEET MAINTENANCE EQUIPMENT

ROI HARNESS TERMINATION FLEXIBILITY

ROI HARNESSES:

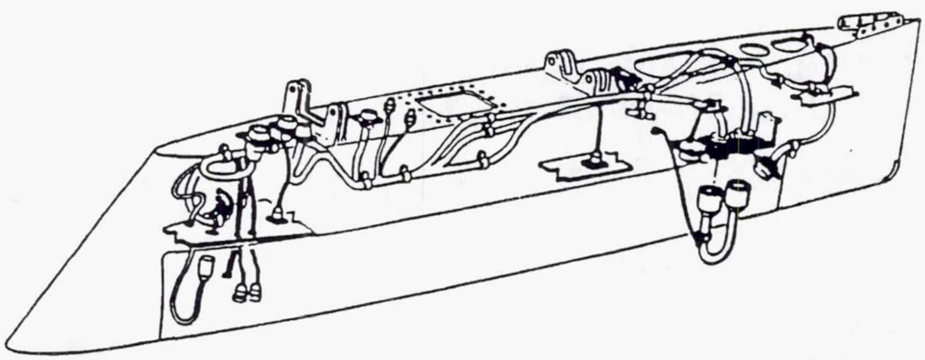
- ARE NOT DESIGN RESTRICTED TO ANY SPECIFIC CONNECTOR TYPE,
- MAY BE TERMINATED USING EITHER RECTANGULAR OR CIRCULAR CONNECTORS,
- ARE COMPATIBLE WITH MOST MILSPEC CONNECTORS,
- MAY BE CRIMPED OR SOLDERED, AND
- THE WIRES TERMINATE DIRECTLY INTO ALL CONNECTORS WITHOUT THE USE OF ANY TRANSITIONAL ELEMENT

ROI HARNESSES REDUCE BATTLE DAMAGE EFFECTS

- ROI HARNESSES SUSTAIN MINIMAL DAMAGE FROM PROJECTILE PENETRATION AS COMPARED TO CONVENTIONAL WIRING BUNDLES,
- ROI DESIGN EXPEDITES BATTLE DAMAGE ASSESSMENT AND REPAIRS,
- DAMAGED RIBBONS ARE "ZIPPED" BACK TOGETHER WITH STANDARD CRIMP SPLICES WITHOUT THE NEED FOR I.D. MARKING,
- REPLACING SEVERLY DAMAGED ROI HARNESSES IS PLAUSIBLE AND GREATLY SIMPLIFIED COMPARED TO REPLACING CONVENTIONAL SPIDER HARNESSES.

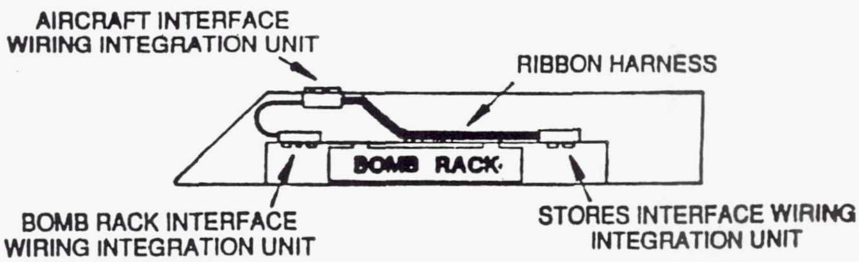
A-6E RELIABILITY & MAINTAINABILITY (R&M) PYLON

ORIGINAL WEAPONS CONTROL SYSTEM IMPROVEMENT (WCSI) PYLON DESIGN



A-6E R&M PYLON

PYLON ROI LAYOUT



V-22 WIRING IMPROVEMENT STUDY WEIGHT SUMMARY 24 JAN 1991

	BASELINE	ROI
MIDWING HARNESS	239 LBS	132 LBS
REDUCTION	------	45%
FULL AIRCRAFT ESTIMATE *	1546 LBS	1185 LBS
REDUCTION	------	23.4%

* EXTRAPOLATED FROM MIDWING RESULTS USING BELL BOEING GROUND RULES.

V-22 WIRING IMPROVEMENT STUDY
COST SUMMARY 24 JAN 1991
(MIDWING AREA ONLY)

	BASELINE	ROI
R&D (NRE)	$ 1,216,600	$ 1,473,300
INVESTMENT (PRODUCTION)	$152,921,900	$110,656,121
O&S (SPARES)	$ 6,108,800	$ 3,571,700
	$160,247,300	$115,701,121
% REDUCTION	------------	28%

1) BASED ON 913 A/C PRODUCTION RUN.

- OWS PROVIDES BENEFITS IN COST, WEIGHT, R&M, E^3 PERFORMANCE, AND GROWTH POTENTIAL
- MODULARITY OF HARNESSES AND WIUs SIGNIFICANTLY IMPROVES WIRING SYSTEM LOGISTICS SUPPORT
- COMPLETE ROI WIRING SYSTEM CURRENTLY BEING DEVELOPED FOR THE V-22
- ORGANIZED WIRING TO BE APPLIED IN FUTURE AIRCRAFT PLATFORMS AND REWIRE PROGRAMS

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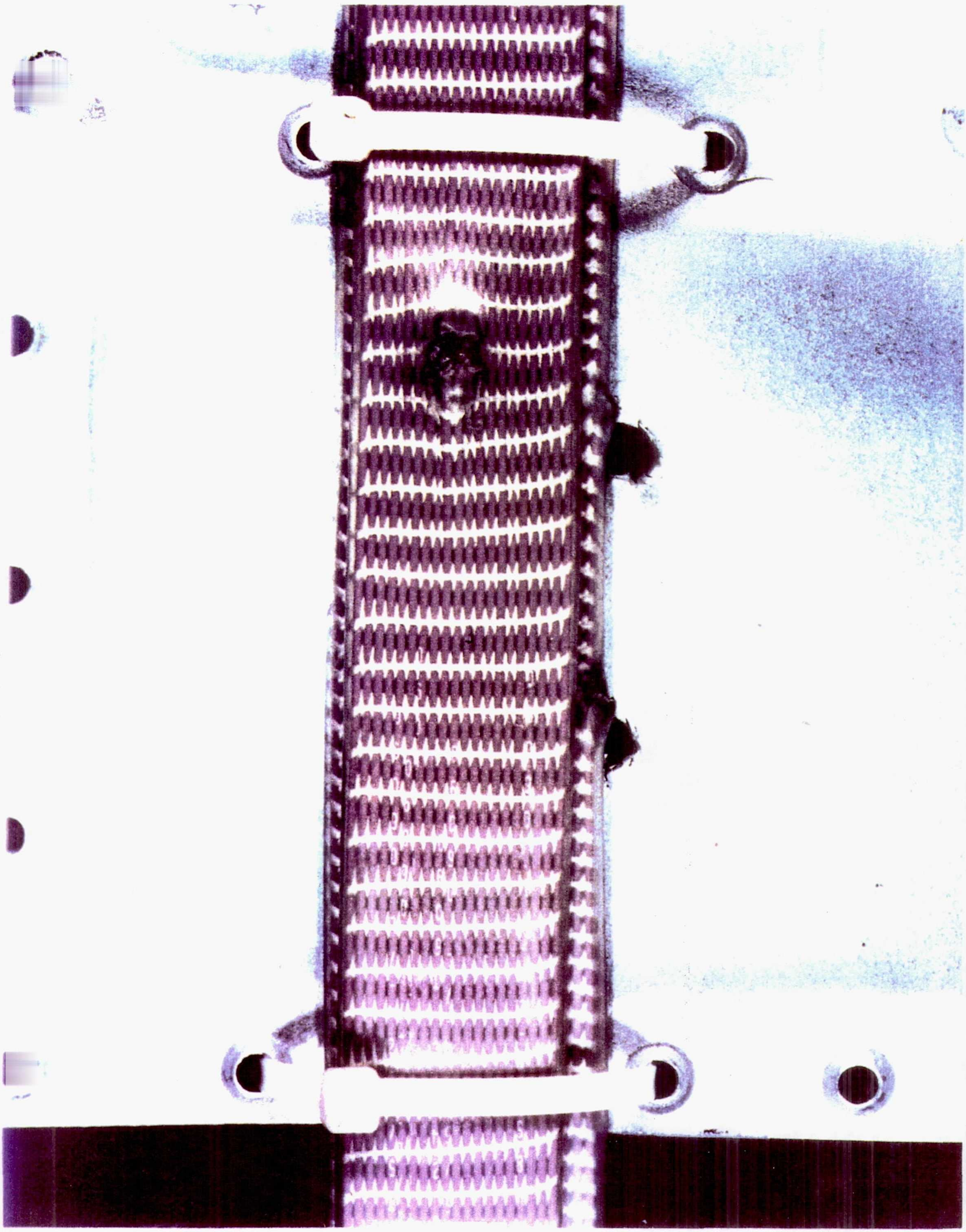

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NEMA WIRE AND CABLE STANDARDS DEVELOPMENT PROGRAMS

Robert W. Baird
National Electrical Manufacturers Association
Washington, DC

NEMA

National Electrical Manufacturers Association

WHAT IS NEMA?

"The National Electrical Manufacturers Association (NEMA) is the Nation's Largest Trade Association for Manufacturers of Electrical Equipment. Its Member Companies Produce Components, End-Use Equipment and Systems for the Generation, Transmission, Distribution, Control and Use of Electricity."

WHAT IS NEMA?

STRUCTURE

- 600 Member Corporations
- Approximately 100 Staff
- $10 Million Annual Budget
- 9 Divisions
- 68 Product Sections
- Affiliate Organizations:
  - Automation Forum (AF)
  - Joint Committee on Business Communications and Productivity (BCP)
  - National Lighting Bureau (NLB)

OUR MISSION

THROUGH NEMA, THESE COMPANIES COOPERATE IN STRIVING:

- **To Meet Customer Needs and Public Interest With World Class Products and Services**
- **To Encourage the Innovative Application of Existing and Emerging Technology To Electrical Products**
- **To Accelerate the Growth and Enhance the Vitality of the Industry**

OUR MISSION

Through The Cooperative Efforts of Its Members and Staff NEMA Pursues Its Mission by:

1. Engaging in the Development of Codes and Standards

2. Promoting Safety in the Manufacture and Use of Electrical Products

3. Communicating Appropriate Information About the Industry

4. Advocating its Views to Government Bodies and Other Interested Parties on Matters Affecting the Industry

5. Conducting Educational Forums

6. Promoting the Industry

WHAT IS NEMA?

PRODUCT ORIENTATION

- Industrial Automation
- Lighting Equipment
- Electronics
- Industrial Equipment
- Building Equipment
- Insulating Materials
- Wire and Cable
- Power Equipment
- Diagnostic Imaging and Therapy Systems

WHAT IS NEMA?

Activities

- National and International Standards
- Statistics
- Public Relations
- International Affairs
- Government Affairs
- Environmental Affairs
- Legal Affairs
- Market Relations
- Jointly Funded Research
- Education and Training

WIRE AND CABLE DIVISION

- 6 Sections
  - Building Wire and Cable
  - Fabricated Conductors
  - Flexible Cords
  - High Performance Wire and Cable
  - Magnet Wire
  - Power and Control Cable
- 60 Member Companies
- 5 Staff

WIRE AND CABLE DIVISION

Fabricated Electrical Conductors

Uninsulated electrical conductors, solid or composite-strands, fabricated of copper or copper alloys, bar or metal-coated.

******

Camden Wire Company	Nesor Alloy Company
Hudson International	Wyre Wynd, Inc.

WIRE AND CABLE DIVISION

Magnet Wire Section

Insulated conductors of the types generally used in the creation of an electromagnetic field.

******

Alcatel Canada Wire, Inc.

American Wire Corporation

Bridgeport Insulated Wire Co.

Chicago Magnet Wire Corporation

Elektrisola, Inc.

Essex Group

Magnatek Lighting Products

Optec DD, USA, Inc.

Phelps Dodge Magnet Wire

Rea Magnet Wire Company

Southwire Specialty Products

Westinghouse Electric Corp.

WIRE AND CABLE DIVISION

Flexible Cords Section

Fixture and appliance wires and flexible cords including power supply cords, cord sets, and extension cords, with or without a molded on fitting or an attached wiring device.

******

American Electric Cordsets

Belden

Carol Cable Company

Coleman Cable and Wire Company

Essex Group

General Cable Company

Leviton Mfg. Company

Pacific Electricord

Triangle Wire and Cable Company

Woods Wire Products

WIRE AND CABLE DIVISION

Building Wire and Cable Section

Building wire and cable including thermoplastic, thermoset, non-metallic, service entrance, armor and metal clad, underground feeder, machine tool, and branch circuit wire and cables.

******

Alcan Cable

Carol Cable Company

Coleman Cable Corporation

Colonial Wire and Cable

General Cable Company

Okonite Company

Pacific Electricord Company

Pirelli Cable Corporation

Rome Cable Corporation

Royal Electric

Southwire Company

Triangle Wire and Cable

WIRE AND CABLE DIVISION

Power and Control Cable Section

Solid dielectric insulated wire and cables including thermosetting, thermoplastic, single and multiconductor, jacketed, sheathed or armored for power and control applications.

******

Alcan Cable

Alcatel Chester Cable Corp.

Amercable

BICC Cables Corp.

Cablec Continental Cables Co.

Carol Cable Company

Furon Company

The Kerite Company

The Okonite Company

Pirelli Cable Corporation

The Rockbestos Company

Rome Cable Corporation

Royal Electric

Southwire Company

Triangle Wire and Cable

WIRE AND CABLE DIVISION

High Performance Wire and Cable Section

Insulated signal and communications cable, coaxial cable, hook-up wire, appliance wiring material, power-limited circuit cable, thermocouple wire, shipboard cables, airframe and automotive wire and cable.

American Electric Cable

Astro Industries

AT&T

Barcel Wire and Cable Corp.

Berk-Tek, Inc.

Brand-Rex

Cablec Continental Cables Corp.

Cable USA, Inc.

Cooper Industries/Belden

Delta Surprenant Wire and Cable

Furon Company

Harbor Industries

Helix/Hitemp Cables

Independent Cable, Inc.

Kris-Tech Wire Company

Champlain Cable Corp.

Micro-Tek Corporation

Mohawk Wire and Cable Company

Montrose Product Company

The Okonite Company

Pacific Electricord Company

Carol Cable Company

Philadelphia Insulated Wire

Prestolite Wire Corporation

Quirk Wire Company

Radix Wire Company

The Rockbestos Company

Siecor Corporation

Speciality Cables Corp.

Tensolite Company

Times Microwave Systems

Triangle Wire and Cable

WIRE AND CABLE DIVISION

Activities

- National and International Standards
- Statistics
- Public Relations
- International Affairs
- Government Affairs
- Environmental Affairs
- Legal Affairs
- Market Relations
- Jointly Funded Research

WIRE AND CABLE DIVISION

Technical Liaisons

- UL
- CSA
- NFPA
- EEMAC
- EIA
- ICEA
- ASTM
- SPI
- DESC
- NAVSEA
- NAVAIR
- NASA
- Other Supplier and User Groups

WIRE AND CABLE DIVISION

NEMA Wire and Cable Standards

HP 3-1987 (R1992)	Electrical and Electronic PTE (Polytetrafluro-ethylene) Insulated High Temperature Hook-Up Wire (600 Volt), EE (1000 Volt), and ET (250 Volt)
HP 4-1988	Electrical and Electronic FEP Insulated High Temperature Hook-Up Wire, Type K, KK, and KT
HP 100-1991	High Temperature Instrumentation and Control Cables (Set)
HP 100.1-1991	High Temperature Instrumentation and Control Cables Insulated and Jacketed with FEP Flourocarbons
HP 100.2-1991	High Temperature Instrumentation and Control Cables Insulated and Jacketed with EFTE Flouropolymers
HP 100.3-1991	High Temperature Instrumentation and Control Cables Insulated and Jacketed with Cross-Linked (Thermoset) Polyolefin (XLPO)
HP 100.4-1991	High Temperature Instrumentation and Control Cables Insulated and Jacketed with ECTFE Flouropolymers
MW 750-1984 (R1990)	Dynamic Coefficient of Friction of Film Insulated Magnet Wire
MW 755-1991	Straight Flange Magnet Wire Plastic Spools/Reels
MW 760-1991	Tapered Flange Magnet Wire Plastic Spools/Reels
MW 765-1992	Reclaiming Magnet Wire Plastic Spools/Reels
MW 770-1993	Unified Customer Labeling for Magnet Wire Products
MW 800-1989	Guidelines for Precautionary Labeling of Magnet Wire

WIRE AND CABLE DIVISION

NEMA Wire and Cable Standards (Continued)

MW 1000-1993	Magnet Wire
WC 2-1980 (R1991)	Steel Armor and Associated Coverings for Impregnated-Paper-Insulated Cables (ICEA S-67-401 Fifth Edition)
WC 3-1992	Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (ICEA S-19-1981 Sixth Edition)
WC 4-1988	Varnished-Cloth-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (ICEA S-65-375 Third Edition)
WC 5-1992	Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy
WC 7-1988	Cross-Linked-Thermosetting-Polyethelene-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (ICEA S-66-524)
WC 8-1988	Ethylene-Propylene-Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (ICEA S-68-516)
WC 26-1990	Wire and Cable Packaging
WC 50-1976 (R1988)	Ampacities, Including Effect of Shield Losses for Single-Conductor Solid-Dielectric Power Cable 15Kv through 69 kV (ICEA P-53-426 Second Edition)
WC 51-1986 (R1991)	Ampacities of Cables in Open-Top Cable Trays (ICEA P-54-440 Third Edition)

WIRE AND CABLE DIVISION

NEMA Wire and Cable Standards
(Continued)

WC 52-1984 (R1991)	High Temperature and Electronic Insulated Wire-Impulse Dielectric Testing
WC 53-1990	Standard Test Methods for Extruded Dielectric Power, Control, Instrumentation, and Portable Cables (ICEA T-27-581)
WC 54-1990	Guide for Frequency of Sampling Extruded Dielectric Power, Control, Instrumentation, and Portable Cables for Test (ICEA T-26-465)
WC 55-1992	Instrumentation Cables and Thermocouple Wire (ICEA S-82-552)
WC 56-1986	3.0 kHz Insulation Continuity Proof Testing of Hook-Up Wire
WC 57-1990	Standard for Control Cables (ICEA S-73-532)
WC 58-1991	Standard for Portable and Power Feeder Cables for Use in Mines and Similar Applications
WC 61-1992	Transfer Impedence Testing
WC 62-1992	Repeated Spark/Impulse Dielectric Testing

WIRE AND CABLE DIVISION

1993 Technical Activities

- UL/CSA Standards Harmonization
  - UL 62/CSA 49
  - UL 817/CSA 21
  - UL 758/CSA 210.2
- NEMA Standards Revisions
  - MW 1000
  - WC 3
  - WC 5
  - WC 7
  - WC 8
  - WC 53
  - WC 54
  - WC 56
  - WC 57
  - WC 58
- Participation/Support of ICEA Standards Development
- Development of Proposals for 1996 National Electrical Code
- Development of Input to UL PVC Compound Recognition Program
- Development of Proposed Revision to UL 719 Joint-pull Test
- Development of Proposed Updates to UL and ASTM Requirements for Compressed Strand Wire
- Development of Proposed Update to MIL-C-17

WIRE AND CABLE DIVISION

1993 Technical Activities (Continued)

- Development of Proposed WC 63 on Premises Wiring Cables
- Consideration of Proposed NEMA Testing Methods for Dry Arc Tracking
- Consideration of Metrication Requirements
- Develop Input to ISO/TC 20 on Aircraft Wire and Cable
- Development of Proposed Bar Coding Standards for Wire and Cable Products
- Development of Proposed Commercial Item Description for Plenum Cable
- Development of Response on Military Prohibition of Silver Plated Conductors - MIL-STD-454
- Development of Proposed Revision to MIL-C-24640
- Round-robin Testing of Hybrid Wire Types
- Provide Input to MIL-C-27500
- Provide Input to MIL-W-22759 Polytetrafluoroethelyne/ Polymide Insulated Wire and Cable
- Provide Input to MIL-W-16878

WIRE AND CABLE DIVISION

- Diversity of Activity
- Changing to Reflect a Changing World
- Faster Paced
- Attuned to the Membership
- Attunded to Members' Markets

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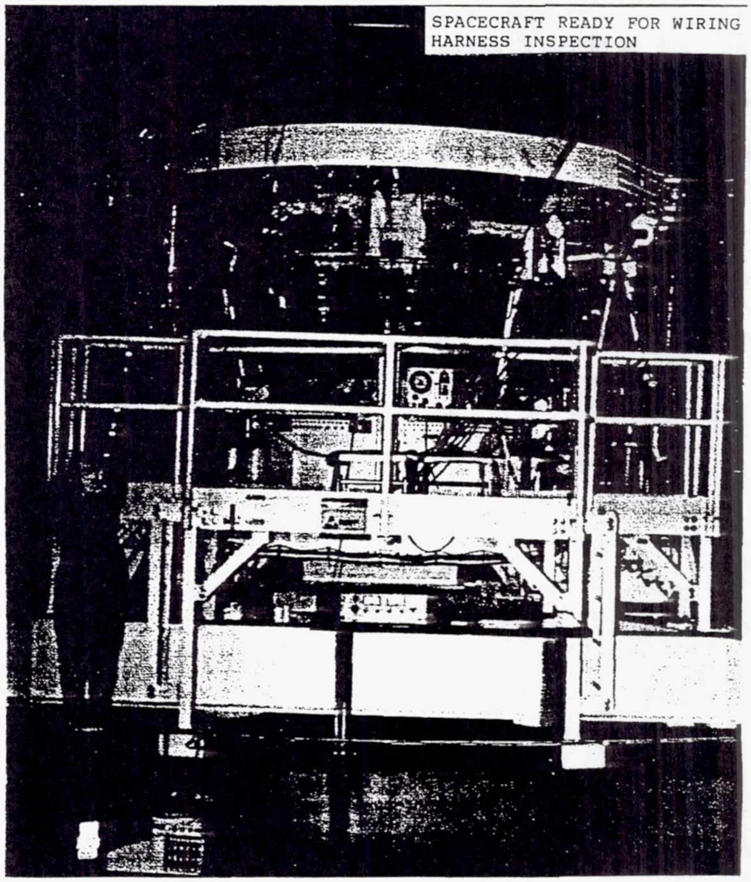
MSFC INSPECTIONS OF INSTALLED POLYIMIDE WIRE

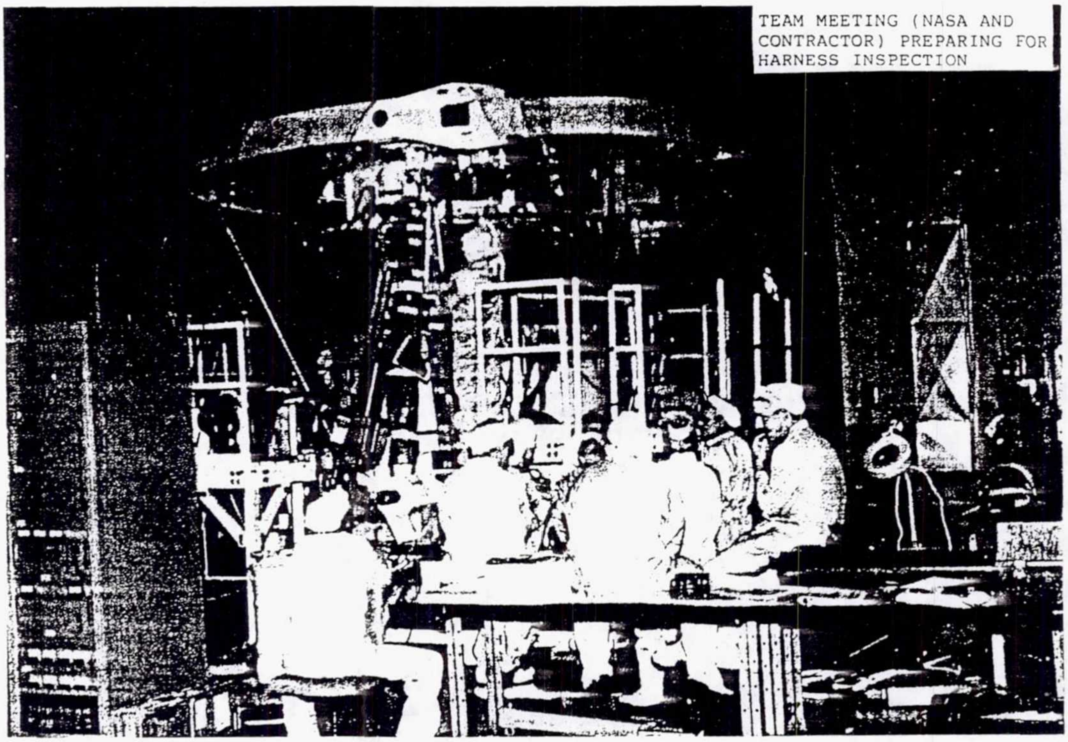
Joe C. Landers
NASA George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

MSFC INSPECTIONS OF INSTALLED POLYIMIDE WIRE HARNESSES

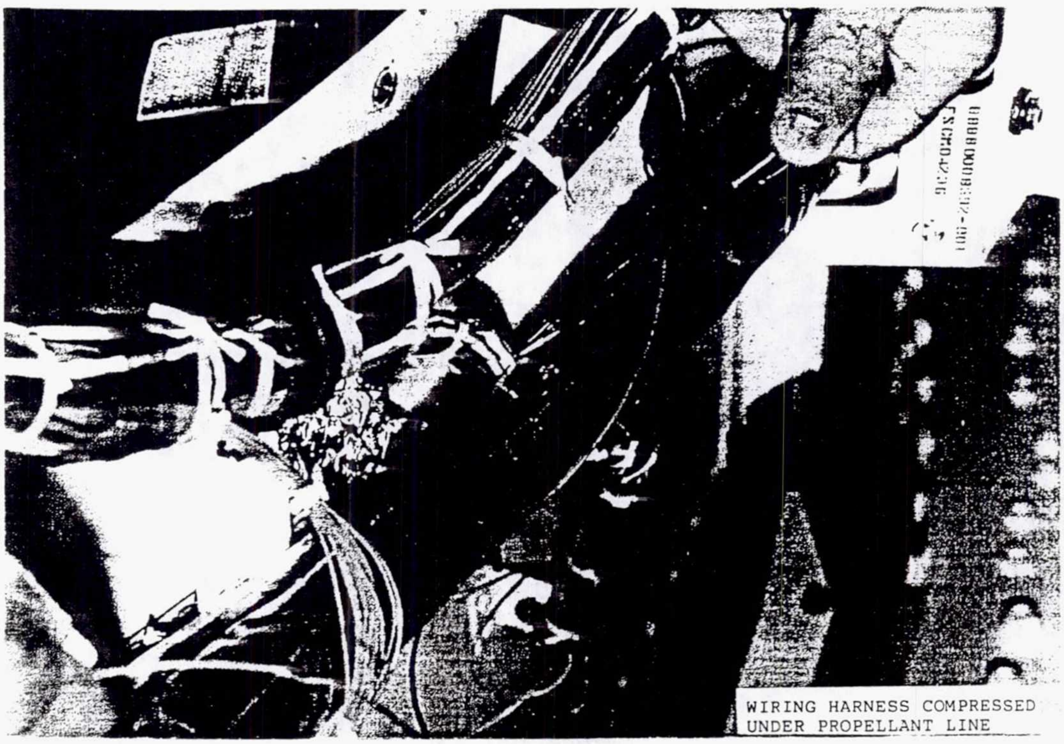
- AN ALERT WAS ISSUED BECAUSE OF THE ARC-TRACKING POSSIBILITIES OF THIS TYPE OF WIRE
- MSFC UNDERTOOK A PROGRAM TO TRY TO ENHANCE THE SAFETY AND RELIABILITY OF THESE HARNESSES
- ONE ELEMENT OF THIS PROGRAM WAS INSPECTION OF INSTALLED WIRING HARNESSES
- PHOTOGRAPHS WILL BE PRESENTED SHOWING THE NEED FOR SUCH INSPECTIONS



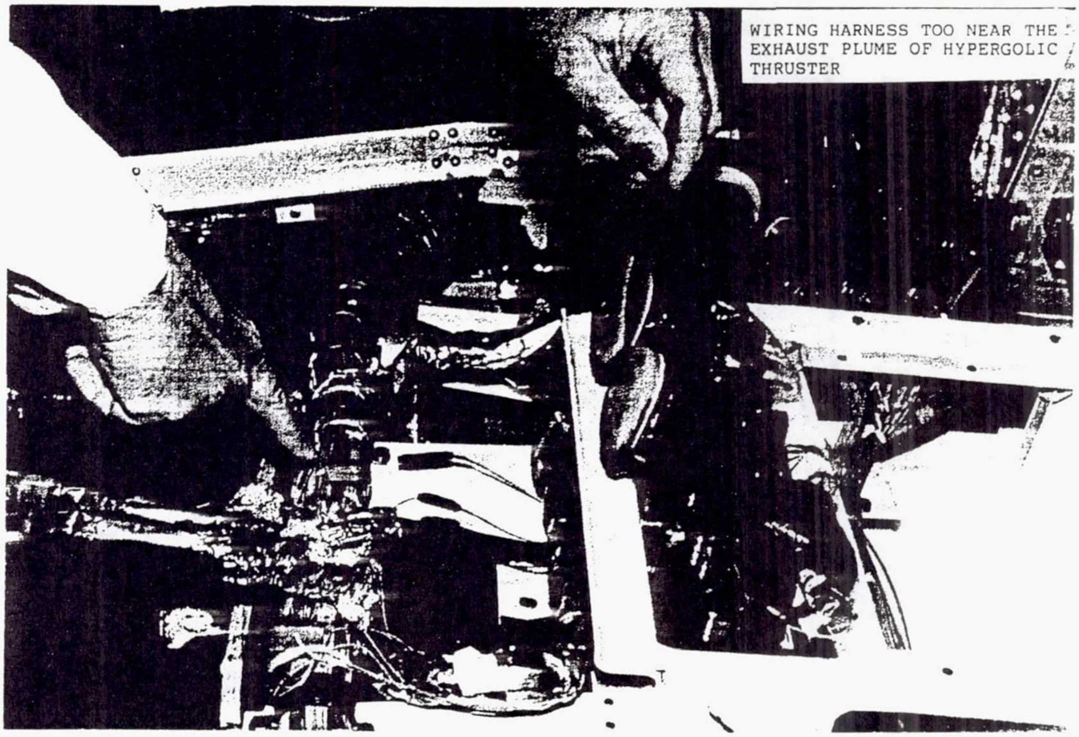
SPACECRAFT READY FOR WIRING HARNESS INSPECTION

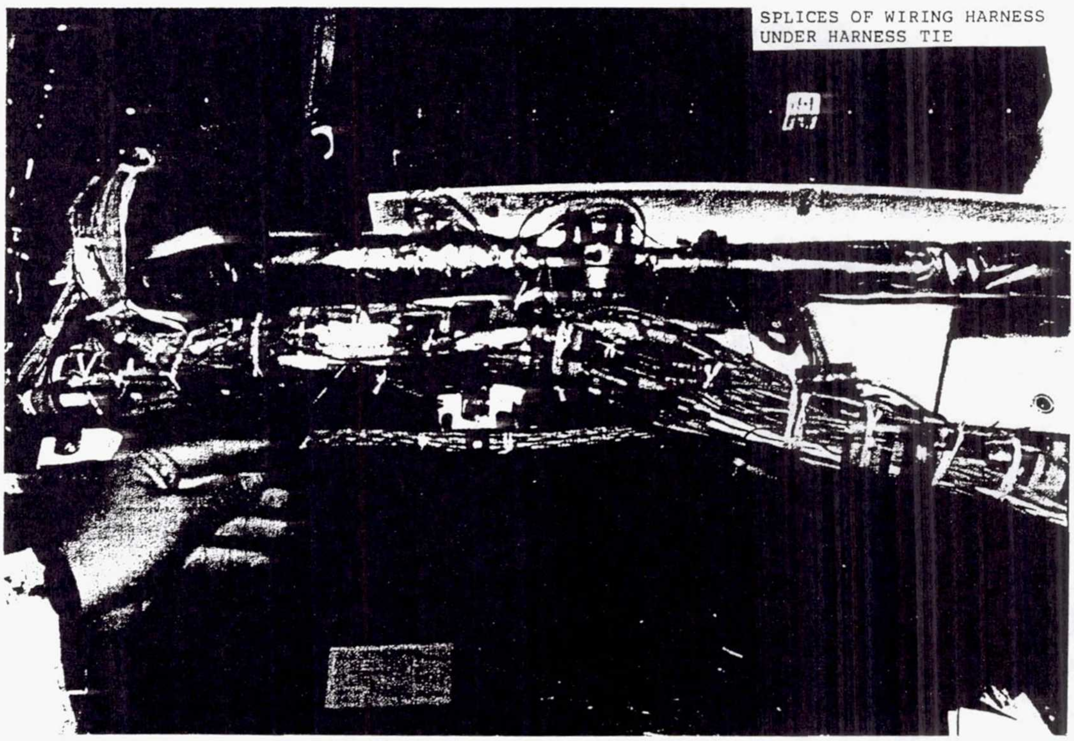


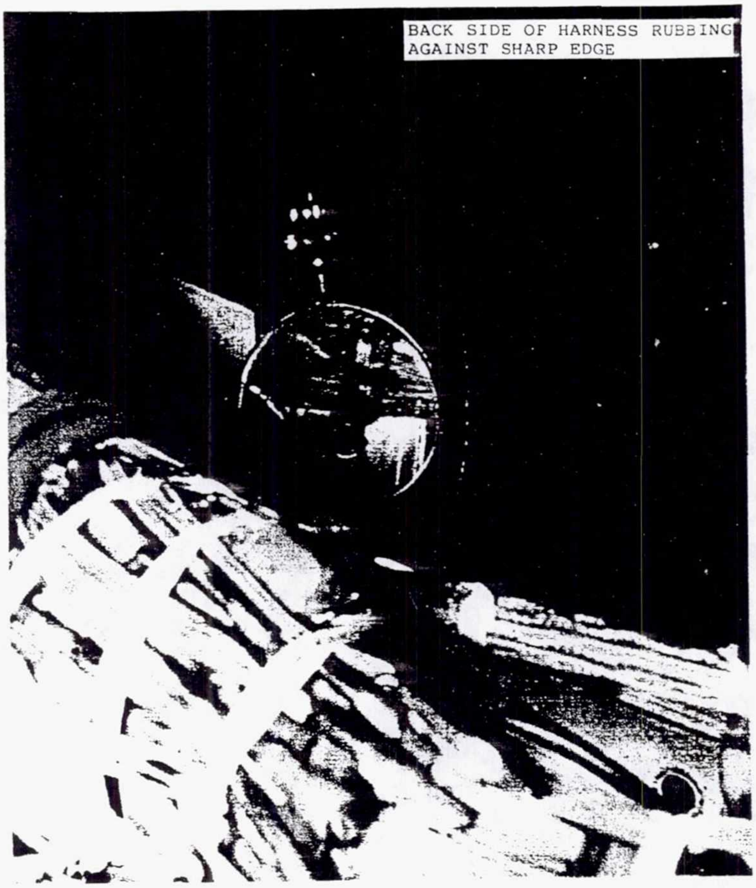
TEAM MEETING (NASA AND CONTRACTOR) PREPARING FOR HARNESS INSPECTION



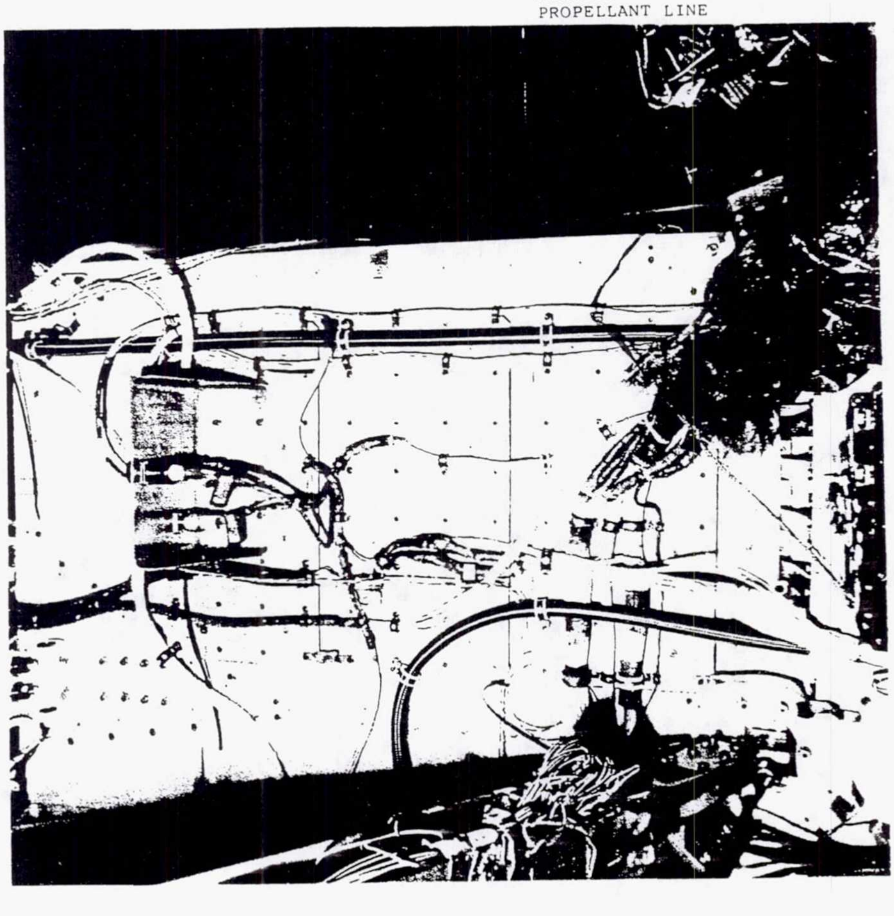
WIRING HARNESS COMPRESSED UNDER PROPELLANT LINE

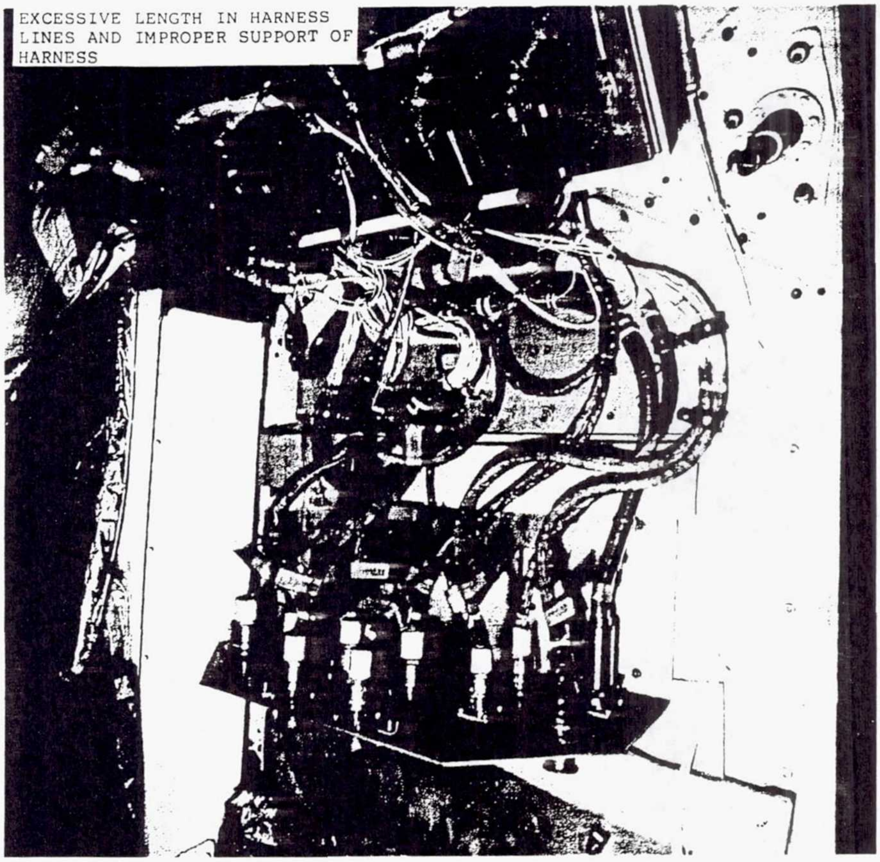

WIRING HARNESS TOO NEAR THE
EXHAUST PLUME OF HYPERGOLIC
THRUSTER

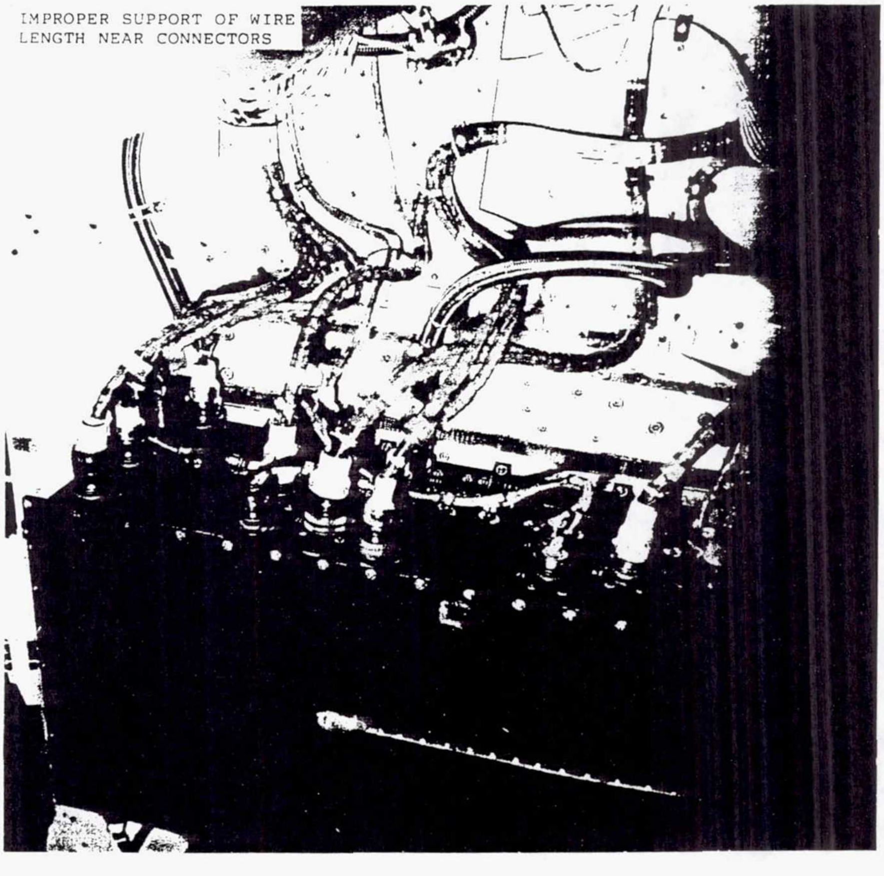

SPLICES OF WIRING HARNESS
UNDER HARNESS TIE

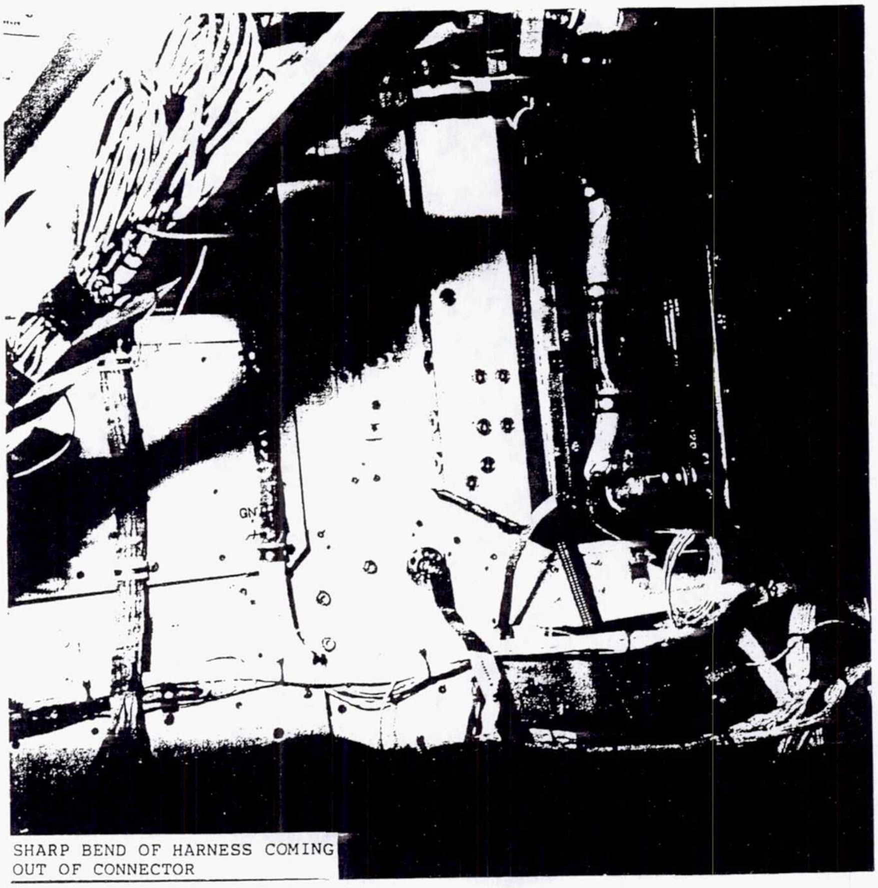


HARNESS UNDERNEATH BRAIDED
PROPELLANT LINE

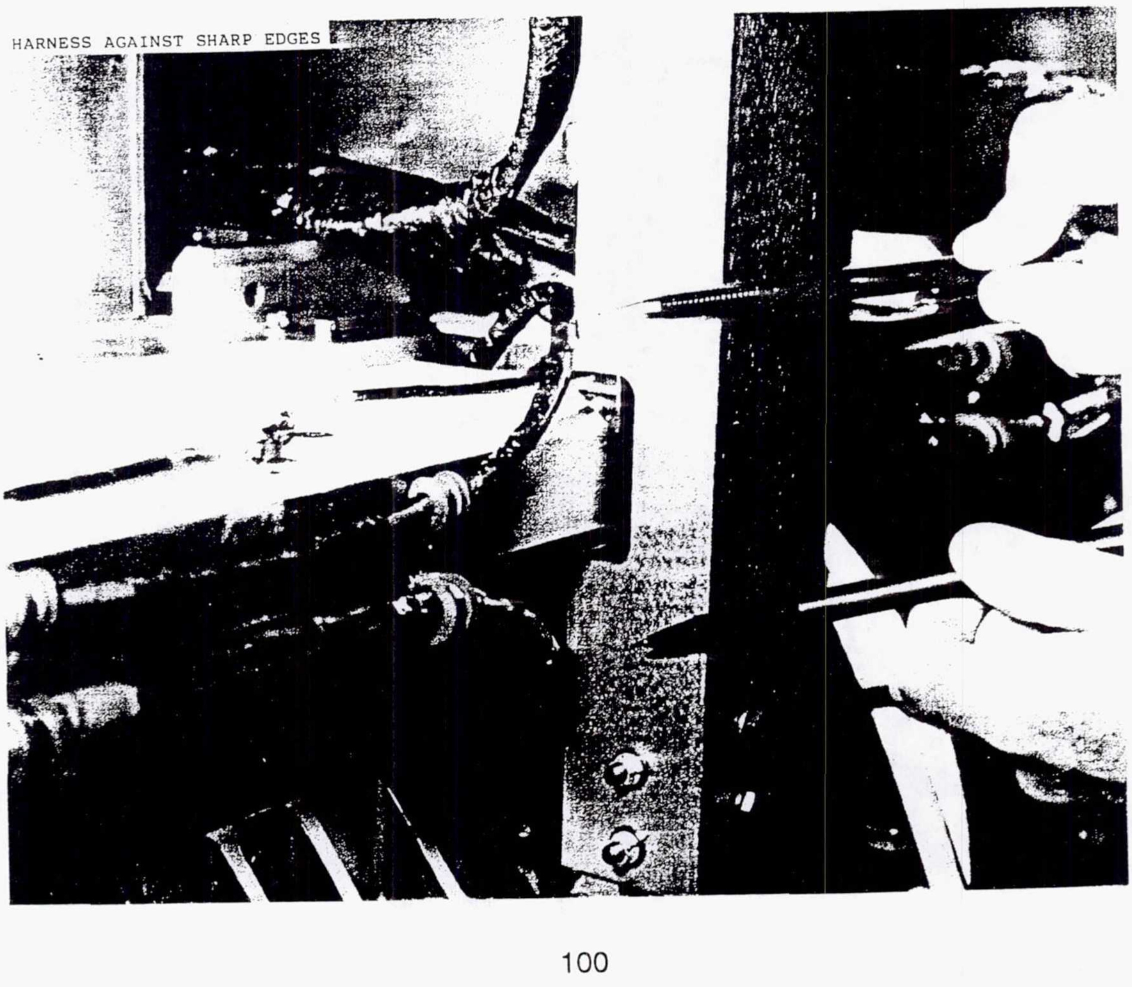



EXCESSIVE LENGTH IN HARNESS LINES AND IMPROPER SUPPORT OF HARNESS

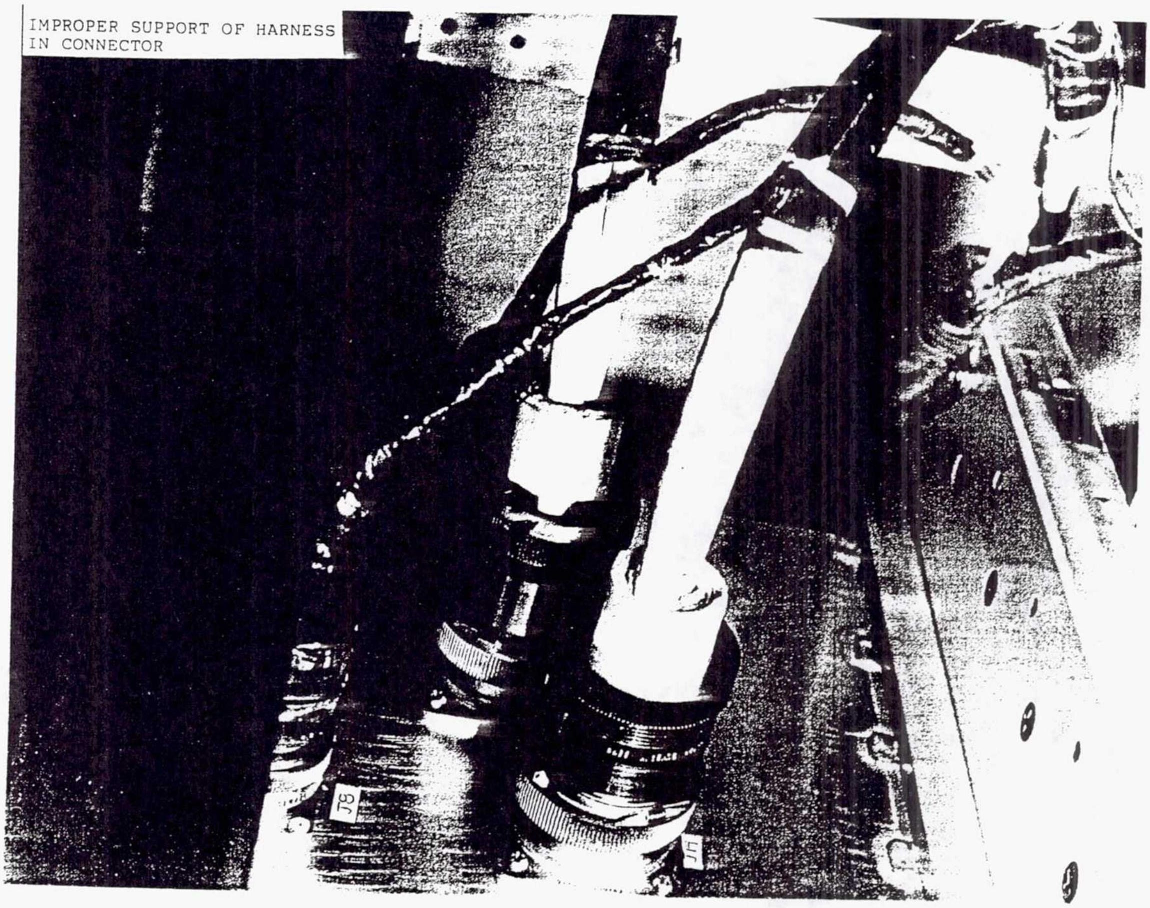

IMPROPER SUPPORT OF WIRE LENGTH NEAR CONNECTORS



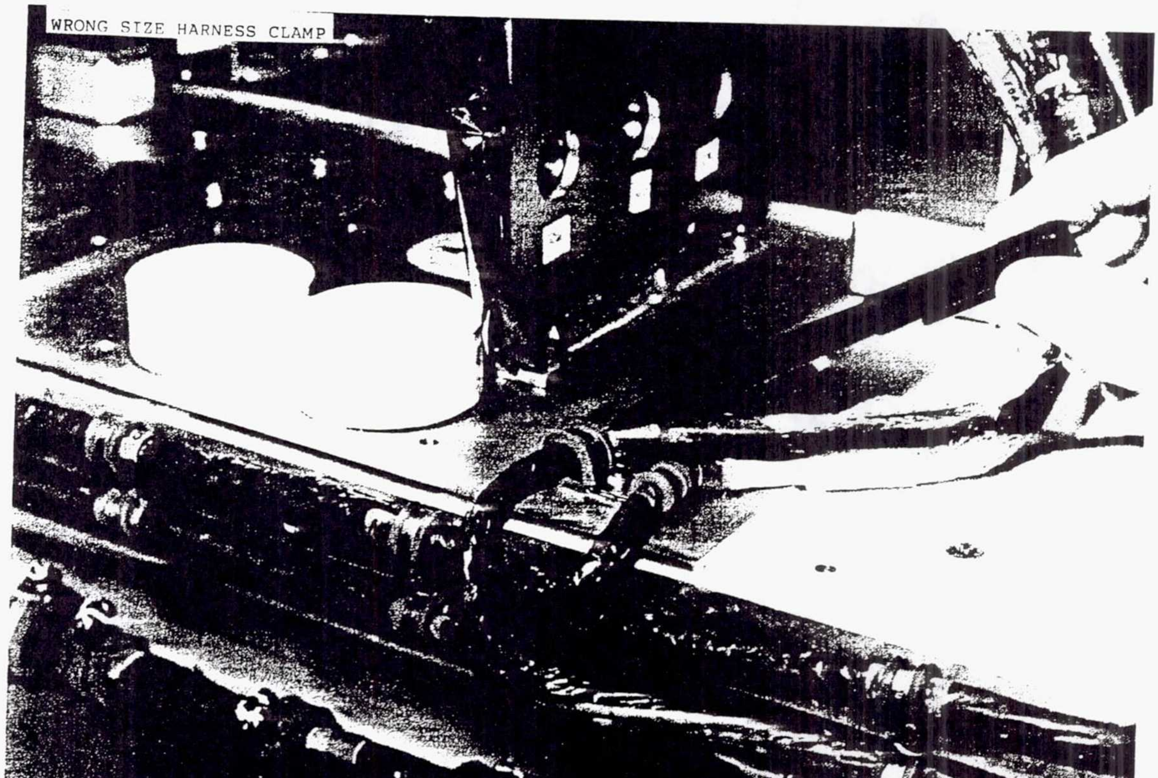
SHARP BEND OF HARNESS COMING OUT OF CONNECTOR



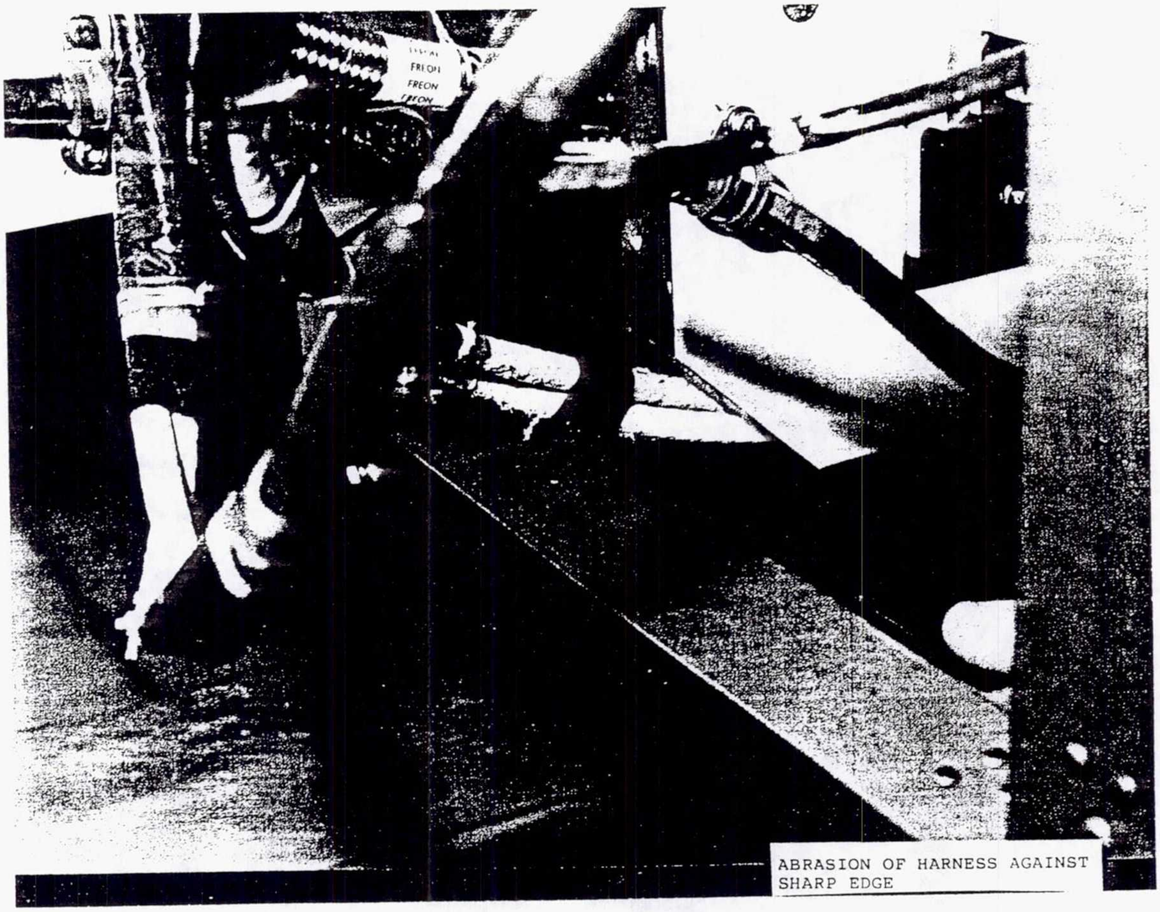
HARNESS AGAINST SHARP EDGES



IMPROPER SUPPORT OF HARNESS IN CONNECTOR



WRONG SIZE HARNESS CLAMP



ABRASION OF HARNESS AGAINST SHARP EDGE

SESSION III

WIRING TEST RESULTS

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WIRING FOR SPACE APPLICATIONS PROGRAM

Ahmad Hammoud
Sverdrup Technology, Inc.
Cleveland, Ohio

INSULATION TESTING AND ANALYSIS

- IDENTIFY AND PRIORITIZE NASA WIRING REQUIREMENTS
- SELECT CANDIDATE WIRING CONSTRUCTIONS
- DEVELOP TEST MATRIX AND FORMULATE TEST PROGRAM
- MANAGE, COORDINATE, AND CONDUCT TESTS
- ANALYZE AND DOCUMENT DATA. ESTABLISH GUIDELINES AND RECOMMENDATIONS

TEST PROGRAM

CANDIDATE SYSTEMS:

- FILOTEX
- THERMATICS
- TENSOLITE
- GORE
- M 81381
- M 22759
- SILICONE RUBBER
- TEFLON

CONFIGURATION:

- MIL-W-81381 & MIL-W-22759 CONSTRUCTIONS
- AWG: #12, #20
- SINGLE WIRE
- TWISTED PAIR
- BUNDLING

WIRING CONSTRUCTIONS

SAMPLE	INSULATION SYSTEM
FILOTEX	PTFE / PI/ FEP
THERMATICS	PTFE / PI / PTFE
TENSOLITE	PTFE / PI / PTFE
GORE	PTFE / HS PTFE / PTFE
81381	FEP / PI
22759	XL - TEFZEL (ETFE)
SILICONE RUBBER	SILICONE RUBBER
TEFLON	TFE

PARTICIPATING ORGANIZATIONS

- McDONNELL AEROSPACE COMPANY
- NASA LeRC: ELECTRO-PHYSICS BRANCH
  MICROGRAVITY COMBUSTION BRANCH
- NASA JSC: WHITE SANDS TEST FACILITY
- NASA MSFC: MATERIALS & PROCESSES LABORATORY
  SPACE ENVIRONMENTAL EFFECTS LABORATORY
- NASA GSFC: PARTS PROJECT OFFICE (NPPO)
- NAVAL AIR WARFARE CENTER (NAWC)
- UNIVERSITY AT BUFFALO

TEST PLAN

McDONNELL AEROSPACE COMPANY

- AC CORONA
- TIME / CURRENT TO SMOKE
- WIRE FUSE TIME
- ABRASION & FLEX LIFE
- DYNAMIC CUT-THROUGH

NASA LeRC ELECTRO-PHYSICS BRANCH

- I & V LEVELS TO INITIATE & SUSTAIN ARC TRACKING
- DC & AC (400 Hz, 20 kHz)
- VACUUM (10^{-6} TORR) AND TEMPERATURE (200° C)

NASA MICROGRAVITY COMBUSTION BRANCH

- IGNITION, FLAMING, SPREAD RATE
- OFFGASSING, SMOKING, TOXICITY
- NORMAL (1g) AND LOW GRAVITY (10^{-2} g)
- OXYGEN, VACUUM, TEMPERATURE

NASA JSC WHITE SANDS TEST FACILITY

- FLAMMABILITY
- ODOR, OFFGASSING
- THERMAL VACUUM STABILITY
- RESISTANCE TO AEROSPACE FLUIDS

NASA MSFC MATERIALS AND PROCESSES LAB

- FLAMMABILITY & ARC TRACKING
- OXYGEN, HIGH TEMPERATURE, VACUUM

NASA MSFC SPACE ENVIRONMENTAL EFFECTS LAB

- THERMAL / ATOMIC OXYGEN EXPOSURE
- ULTRAVIOLET RADIATION, VACUUM
- COMBINED STRESSING (LEO)

UNIVERSITY AT BUFFALO

- DC & 400 Hz BREAKDOWN STRENGTH
- INSULATION RESISTANCE WITH TEMPERATURE
- MULTI-STRESS

NASA GSFC AND NAWC

- TEST COORDINATION
- QUALIFICATION & CERTIFICATION

PLANNED ACTIVITIES

- DOWN-SELECT WIRING CANDIDATES
- DEVELOP TEST MATRIX
- INVESTIGATE NEW CONSTRUCTION / MATERIALS:
  - TRW PFPI
  - 3M FPE FILM
  - FOSTER MILLER PBZT POLYMERS
  - ICI UPILEX

FLAMMABILITY, ODOR, OFFGASSING, THERMAL VACUUM STABILITY, AND COMPATIBILITY WITH AEROSPACE FLUIDS OF WIRE INSULATIONS

David Hirsch
Lockheed
Las Cruces, New Mexico

and

Harry Johnson
NASA White Sands Test Facility
Las Cruces, New Mexico

Background

NASA Lewis Research Center Requested NASA Johnson Space Center White Sands Test Facility to Conduct Flammability, Odor, Offgassing, Thermal Vacuum Stability, and Compatibility Tests with Aerospace Fluids of Several Wire Insulations

Wire Insulations Evaluated:
- PTFE Teflon, 12 AWG
- PTFE Teflon, 20 AWG
- Kapton, 12 AWG
- Kapton, 20 AWG
- Teflon/Kapton Hybrid, 12 AWG
- Teflon/Kapton Hybrid, 20 AWG

Tests Performed:

- Per NHB 8060.1C
  - Flammability (Tests 1 and 4)
  - Odor (Test 6)
  - Compatibility with Aerospace Fluids (Test 15)
- Per NHB 8060.1B
  Offgassing (Test 7)
- Per SP-R-0022A (ASTM E 595)
  Thermal Vacuum Stability

Test 1 (Upward Flame Propagation)

Test Approach:

- Exposed Vertical Sample to Ignition Source That Provided 750 Calories for Approximately 25 s
- Three Samples Tested for Each Test Condition

Observations Made:

- Ignitability
- Burn Length
- Ignition of a Witness Material by Transfer of Burning Debris

Test Conditions:

30% Oxygen in Nitrogen at 10.2 psia

Results:

Materials	Burn Length (cm)		
	Sample 1	Sample 2	Sample 3
PTFE Teflon, 12 AWG	0	0	0
PTFE Teflon, 20 AWG	8.1	7.6	6.4
Kapton, 12 AWG	0	0	1.0
Kapton, 20 AWG	0.3	5.8	0
Teflon/Kapton Hybrid, 12 AWG	0.3	1.0	1.0
Teflon/Kapton Hybrid, 20 AWG	1.0	3.8	3.8

Test 4 (Wire Insulation Flammability)

Test Approach:

- Oriented Wire Sample 15 Degrees to Vertical, Internally Heated Sample, and Exposed Sample to Ignition Source Providing 750 Calories for Approximately 25 s
- Tested Three Samples for Each Test Condition

Observations Made:

- Ignitability
- Burn Length
- Ignition of a Witness Material by Transfer of Burning Debris

Test Conditions:

- 30% Oxygen in Nitrogen at 10.2 psia
- Internal Wire Temperatures at 125 and 200 °C

Results:

Materials	Single Wire Burn Length (cm)					
	Samples Tested at 125 °C			Samples Tested at 200 °C		
PTFE Teflon, 12 AWG	2.5	2.5	3.0	3.6	3.3	2.3
PTFE Teflon, 20 AWG	2.0	3.8	4.1	4.8	4.1	4.3
Kapton, 12 AWG	0	0	0	1.0	0.8	0.8
Kapton, 20 AWG	4.1	3.8	4.3	4.1	4.6	4.1
Teflon/Kapton Hybrid, 12 AWG	1.3	0	0	0	0	0
Teflon/Kapton Hybrid, 20 AWG	3.0	2.8	2.5	2.5	4.1	2.5

Test 6 (Odor Assessment)

Test Approach:

- Subject Sample to Thermal Exposure for 72 Hours at 120 °F, 25.9% Oxygen at 11.9 psia
- Odor Panel Members Administered with at Least 30 cc of Gas from Sample Container

Odor Scale Rating	
Undetectable	0
Barely Detectable	1
Easily Detectable	2
Objectionable	3
Revolting	4

Results:

Material	Odor Rating*
PTFE Teflon, 12 AWG	0.8
PTFE Teflon, 20 AWG	1.0
Kapton, 12 AWG	0.8
Kapton, 20 AWG	0.4
Teflon/Kapton Hybrid, 12 AWG	0.4
Teflon/Kapton Hybrid, 20 AWG	0.2

*Average Result of 5 Responses

Test 7 (Determination of Offgassed Products)

Test Approach:

- Subjected Sample to Thermal Exposure for 72 Hours at 120 °F, 25.9% Oxygen at 11.9 psia
- After Each Sample Container Was Cooled, Determined Identity and Quantity of Each Analyzable Offgassed Product

Material: Teflon, 12 AWG

Component	Toxic Limit (μg/g)	Quantity (μg/g)
C10-C11 Saturated and Unsaturated Aliphatic Hydrocarbons	186.29	0.05
Carbon Monoxide	40.9	0.32
Fluoroaliphatic Hydrocarbons	0.14	0.007
Octamethylcyclotetrasiloxane	217.39	0.005

Test 7
(Determination of Offgassed Products), Cont'd

Material: Teflon, 20 AWG

Component	Toxic Limit (μg/g)	Quantity (μg/g)
C10-C11 Saturated and Unsaturated Aliphatic Hydrocarbons	186.29	0.07
C12 Saturated Aliphatic Hydrocarbon	7.17	0.005
Carbon Monoxide	40.9	0.23
Decamethylcyclopentasiloxane	248	0.005
Fluoroaliphatic Hydrocarbons	0.14	0.006
Hexamethylcyclotrisiloxane	324	0.005
Octamethylcyclotetrasiloxane	217.39	0.006
Xylenes	124	0.02

Material: Kapton, 12 AWG

Component	Toxic Limit (μg/g)	Quantity (μg/g)
Acetaldehyde	77.1	0.005
Carbon Monoxide	40.9	0.17
Hexamethylcyclotrisiloxane	324	0.009
Naphthalene	15.05	0.005
Octamethylcyclotetrasiloxane	217.39	0.005
Toluene	108	0.005
Trimethyl silanol	2.58	0.005

Test 7
(Determination of Offgassed Products), Cont'd

Material: Kapton, 20 AWG

Component	Toxic Limit (μg/g)	Quantity (μg/g)
Acetaldehyde	77.1	0.01
Acetone	1018	0.02
C10 Aromatic Hydrocarbon	0.14	0.008
C8 Ether	167.03	0.005
C9 Saturated Aliphatic Hydrocarbon	7.17	0.005
Carbon Monoxide	40.9	0.17
Hexamethylcyclotrisiloxane	324	0.009
Isopropyl Alcohol	140	0.007
Methyl Alcohol	74.9	0.005
Octamethylcyclotetrasiloxane	217.39	0.006
Trimethyl silanol	2.58	0.01

Material: Teflon/Kapton, 12 AWG

Component	Toxic Limit (μg/g)	Quantity (μg/g)
Acetaldehyde	77.1	0.007
C11 Saturated and Unsaturated Aliphatic Hydrocarbons	17.2	0.01
C9 Aromatic Hydrocarbon	21.5	0.005
Carbon Monoxide	40.9	0.05
Chlorobenzene	65.7	0.005
Hexamethylcyclotrisiloxane	324	0.005
Octamethylcyclotetrasiloxane	217.39	0.005
Toluene	108	0.007

Test 7 (Determination of Offgassed Products), Cont'd

Material: Teflon/Kapton, 20 AWG

Component	Toxic Limit (μg/g)	Quantity (μg/g)
Acetaldehyde	77.1	0.04
Acetone	1018	0.04
Acrolein	0.16	0.005
C10 Saturated Aliphatic Hydrocarbons	7.17	0.02
C11-C12 Saturated and Unsaturated Aliphatic Hydrocarbons	7.17	0.15
C6 Aldehyde	3.44	0.01
C7 Aldehyde	0.14	0.007
C9 Aldehyde	0.14	0.009
Carbon Monoxide	40.9	0.05
Chlorobenzene	65.7	0.005
Decamethylcyclopentasiloxane	248	0.005
Ethyl Alcohol	134	0.005
Hexamethylcyclotrisiloxane	324	0.005
Methyl Alcohol	74.9	0.02
Methyl Ethyl Ketone	84.3	0.02
Nitromethane	71.5	0.02
Octamethylcyclotetrasiloxane	217.39	0.005
Tetrachloroethylene	48.6	0.005
Toluene	108	0.01
Trimethyl silanol	2.58	0.01
Unidentified Component	0.14	0.009

Test 15
(Reactivity of Materials in Aerospace Fluids)

Test Approach:

- During Phase I, Evaluated Gross Compatibility by Exposing Material to Fluid at Ambient Temperature for 2 Hours

- During Phase II, Exposed Material to Fluid for 48 Hours at Maximum System Temperature or 160 °F (Whichever Was Higher)

- Observed Pressure Rise, Fluid Composition, and Material Changes When Compared with Reference Material Exposed to Same Fluid

Immersion Data in Liquid Phase of Dinitrogen Tetroxide

Material	Gas Pressure (psia)		Material Changes	Fluid Visual Changes
	Sample	Reference		
PTFE Teflon, 12 AWG	133	132	None	None
PTFE Teflon, 20 AWG	135	133	None	None
Kapton, 12 AWG	141	131	Yellow to Brown	None
Kapton, 20 AWG	157	132	Rough, Friable	Particulate
Teflon/Kapton Hybrid, 12 AWG	132	131	White to Light Pink	None
Teflon/Kapton Hybrid, 20 AWG	132	130	White to Light Pink	None

Test 15
(Reactivity of Materials in Aerospace Fluids), Cont'd

Immersion Data in Liquid Phase of Dinitrogen Tetroxide

Material	Posttest Fluid Analysis (Non-volatile Residue), mg	
	Sample	Reference
PTFE Teflon, 12 AWG	2.1	1.0
PTFE Teflon, 20 AWG	2.0	1.2
Kapton, 12 AWG	1.4	1.7
Kapton, 20 AWG	21	1.5
Teflon/Kapton Hybrid, 12 AWG	1.5	1.5
Teflon/Kapton Hybrid, 20 AWG	0.6	0.5

Immersion Data in Liquid Phase of Hydrazine

Material	Gas Evolut. Rate (sccm/hr/cm² x 10E4)		Material Changes	Fluid Visual Changes
	Sample	Reference		
PTFE Teflon, 12 AWG	EQ	EQ	None	None
PTFE Teflon, 20 AWG	EQ	EQ	None	None
Kapton, 12 AWG	7.1	3.7	Yellow to Brown Rough, Tacky	Brown and Opaque, Particulate
Kapton, 20 AWG	--	--	Gray to Yellow Rough, Tacky, Friable	Brown and Opaque, Particulate
Teflon/Kapton Hybrid, 12 AWG	EQ	EQ	White to Yellow	Yellow
Teflon/Kapton Hybrid, 20 AWG	EQ	EQ	White to Yellow	Yellow

Test 15
(Reactivity of Materials in Aerospace Fluids), Cont'd

Immersion Data in Liquid Phase of Hydrazine - Posttest Fluid Analysis

Material	Purity (%)	CO^2 (ppm)	Non-Volatile Residue (mg)	Chloride (μg)	Fluoride
PTFE Teflon, 12 AWG	99.7	6	0.1	18.4	2.3
Reference	99.7	6	ND	13.8	ND
PTFE Teflon, 20 AWG	99.6	3	0.6	9.2	ND
Reference	99.6	2	1.0	4.6	ND
Kapton, 12 AWG	99.8	1	110	18.4	6.9
Reference	99.8	6	0.5	9.2	ND
Kapton, 20 AWG	99.6	2	91	69	2.3
Reference	99.6	2	0.3	11.5	2.3
Teflon/Kapton Hybrid,12 AWG	99.6	4	34	9.2	2.3
Reference	99.6	1	0.1	6.9	ND
Teflon/Kapton Hybrid, 20 AWG	99.6	3	37	9.2	2.3
Reference	99.6	1	0.1	9.2	ND

VCM Test

Total Mass Loss and Collected Condensable Materials
from Outgassing in a Vacuum Environment

Test Approach:

- Conditioned Sample for 24 Hours at 23 °C and 50% RH
- Weighed Conditioned Sample and Exposed Sample to Vacuum for 24 Hours (At Least 5 x 10E-5 Torr) and 125 °C
- Condensed Portion of Vapors on Preweighed Collector Maintained at 25 °C
- Posttest Collector and Sample Weight Measurements Yielded Weight Loss and Collected Volatile Condensable Material
- Further Conditioning of Sample for 24 Hours at 23 °C and 50% RH and Weighing Yielded Water Vapor Recovery Values

Results:

Material	Weight Loss (%)	VCM (%)	WVR (%)
PTFE Teflon, 12 AWG	0.06	0.03	0.05
PTFE Teflon, 20 AWG	0.04	0.02	0.02
Kapton, 12 AWG	0.80	0.01	0.60
Kapton, 20 AWG	1.02	0.07;0	0.71
Teflon/Kapton Hybrid, 12 AWG	0.26	0	0.20
Teflon/Kapton Hybrid, 20 AWG	0.30	0.01	0.23

ELECTRICAL AND MECHANICAL TESTING OF WIRE INSULATION FOR SPACE APPLICATIONS

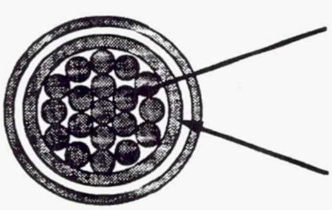
Linda A. Burkhardt
McDonnell Douglas Aerospace
St. Louis, Missouri

BACKGROUND

- PURPOSE
- HYBRID SAMPLES
- TESTING

TEST PROGRAM

M81381/7 VS. GORE HSCR ™



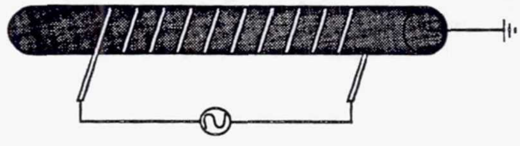
TESTS PERFORMED

- CORONA INCEPTION & EXTINCTION
- TIME/CURRENT TO SMOKE
- WIRE FUSING TIME
- ABRASION
- FLEX LIFE
- DYNAMIC CUT THROUGH

CORONA INCEPTION & EXTINCTION VOLTAGES

-TEST PARAMETERS-

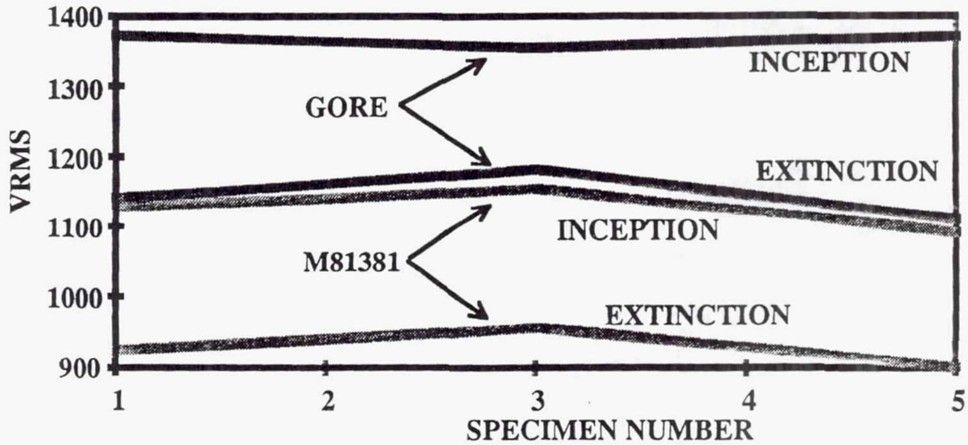
- 1OX MANDREL, 10 TURNS
- 400 HZ POWER SUPPLY
- 50 VOLTS/SECOND
- SEA LEVEL, 60,000 FEET



CORONA INCEPTION & EXTINCTION VOLTAGES

-TEST RESULTS-

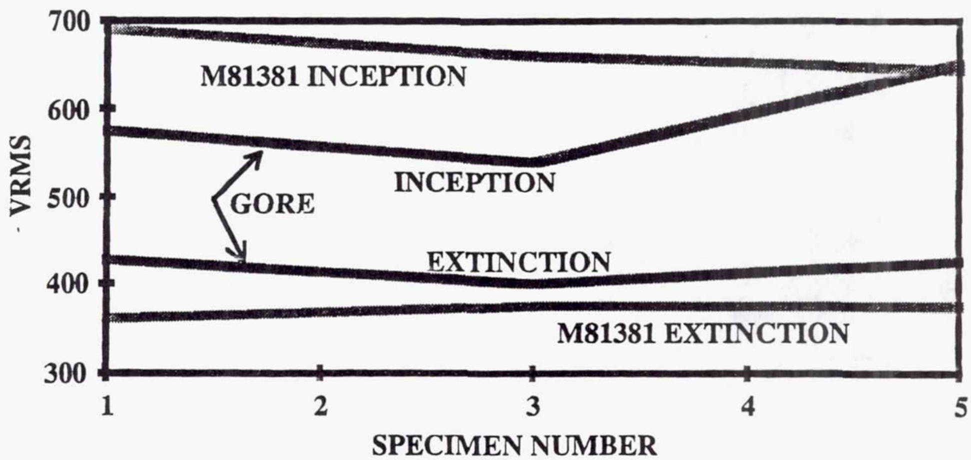
SEA LEVEL



CORONA INCEPTION & EXTINCTION VOLTAGES

-TEST RESULTS-

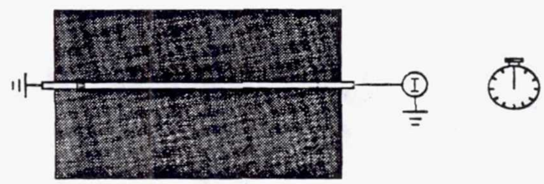
ALTITUDE



TIME/CURRENT TO SMOKE

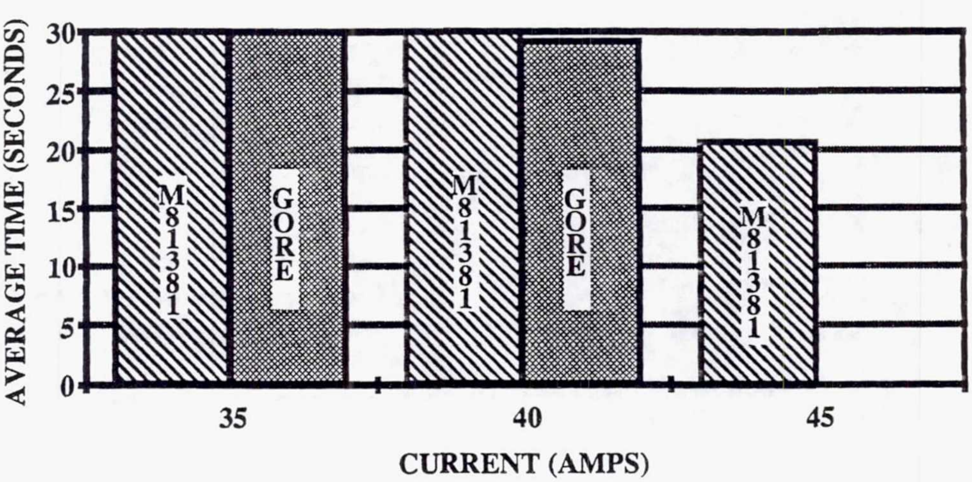
-TEST PARAMETERS-

- SPECIMEN SUSPENDED HORIZONTALLY
- CONSTANT CURRENT DC POWER
- 5 AMP INCREMENTS
- 30 SECONDS AT AMPERAGE



TIME/CURRENT TO SMOKE

-TEST RESULTS-



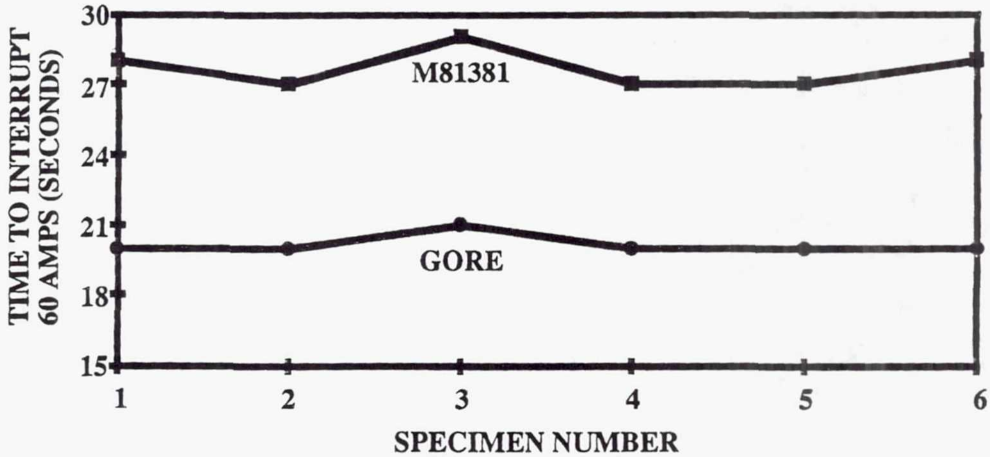
WIRE FUSING TIME

-TEST PARAMETERS-

- SPECIMEN SUSPENDED HORIZONTALLY
- CONSTANT CURRENT DC POWER
- 2.5 X RATED CURRENT (60 A)

WIRE FUSING TIME

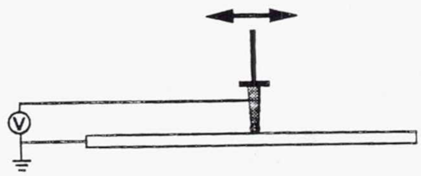
-TEST RESULTS-



ABRASION

-TEST PARAMETERS-

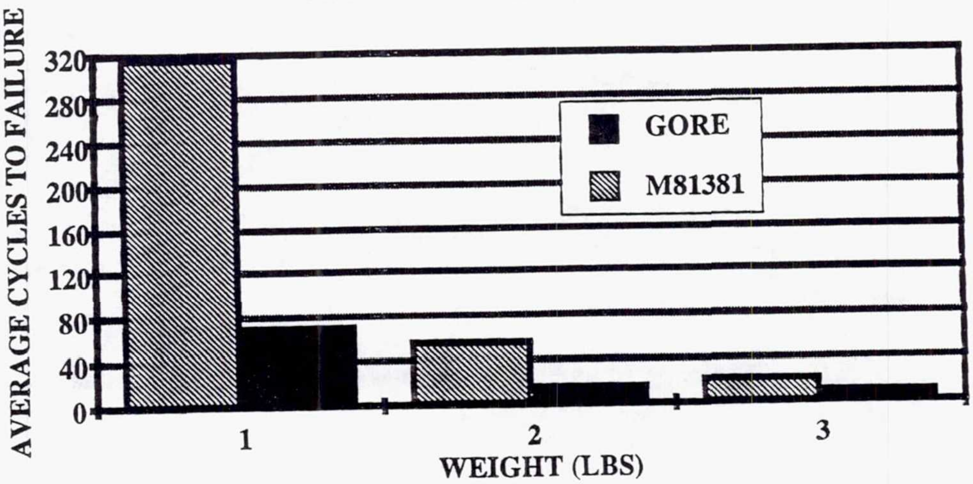
- .020 INCH ROD
- 1 INCH PATH, 60 CYCLES PER MINUTE
- 1, 2, & 3 LB. WEIGHT
- AMBIENT & 150°C



ABRASION

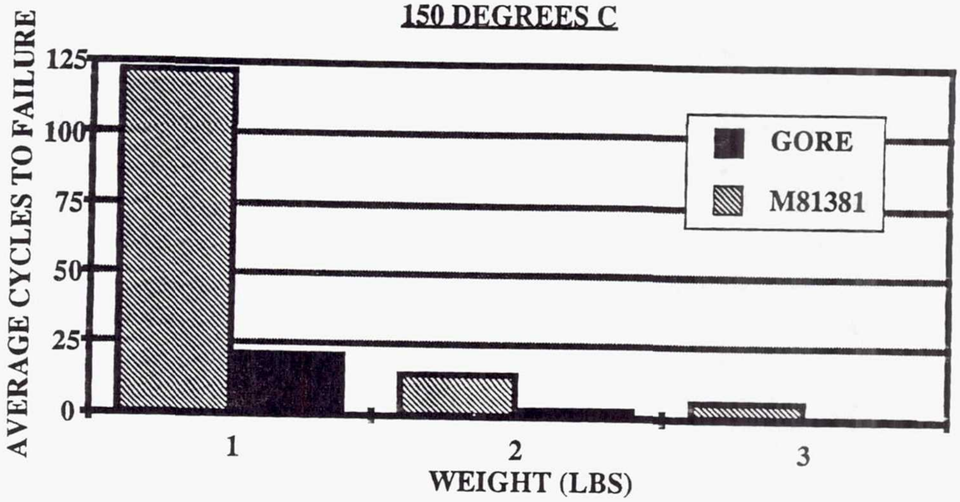
-TEST RESULTS-

AMBIENT TEMPERATURE



ABRASION

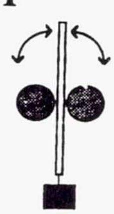
-TEST RESULTS-



FLEX LIFE

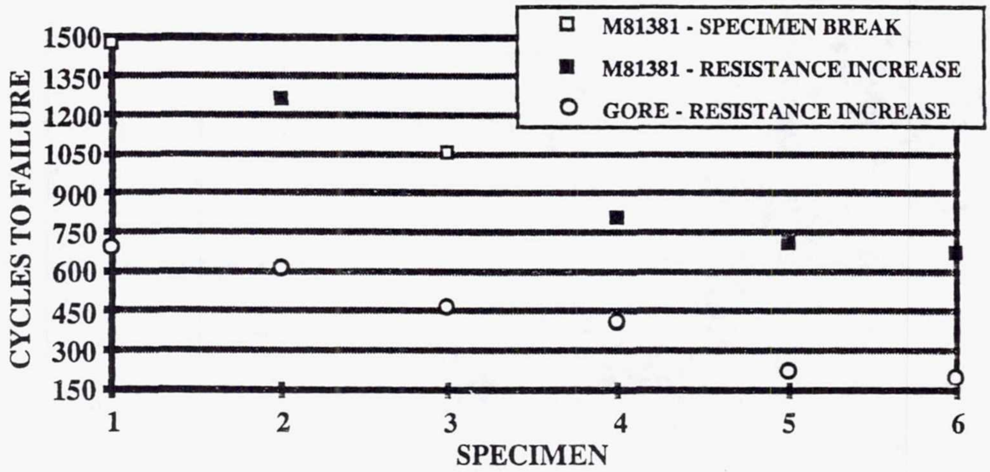
-TEST PARAMETERS-

- 90^{o} FLEX IN EACH DIRECTION
- 30 CYCLES PER MINUTE
- 6X MANDRELS
- 7 LB. WEIGHT



FLEX LIFE

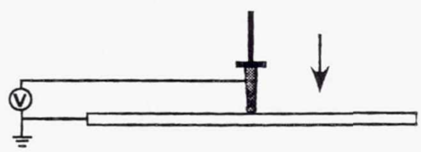
-TEST RESULTS-



DYNAMIC CUT-THRU

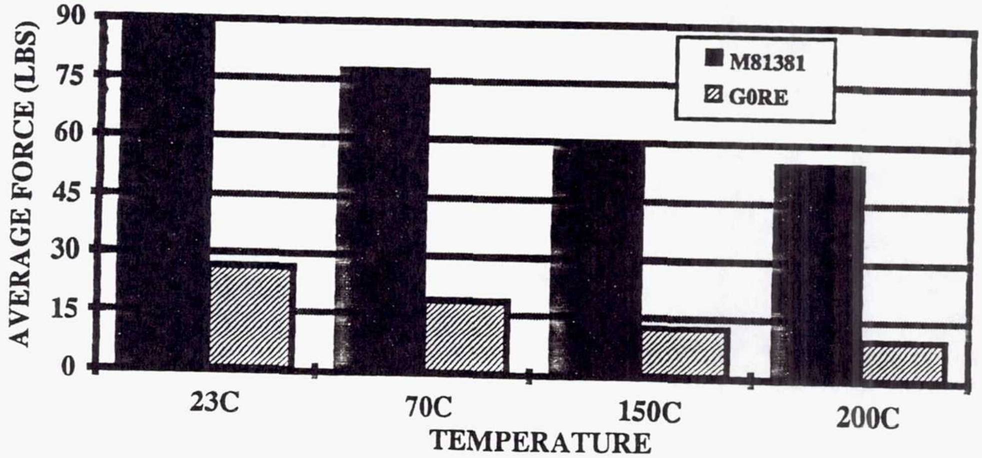
-TEST PARAMETERS-

- .020 INCH ROD
- 600 LB. LOAD CELL
- 0.2 INCH/MINUTE
- 23°C, 70°C, 150°C, & 200°C



DYNAMIC CUT-THRU

-TEST RESULTS-



CONCLUSIONS

- GORE NOT COMPARABLE TO M81381 IN PERFORMANCE AT ELEVATED TEMPERATURES
- MECHANICAL PROPERTIES FAIR BUT M81381 SUPERIOR
- CORONA, WIRE FUSING TIME EQUIVALENT

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EVALUATION OF PYROLYSIS AND ARC TRACKING ON CANDIDATE WIRE INSULATION DESIGNS FOR SPACE APPLICATIONS

Thomas J. Stueber
Sverdrup Technology, Inc.
Lewis Research Center Group
Brook Park, Ohio

and

Kenneth Hrovat
Cleveland State University
Cleveland, Ohio

* NHB 8060.1C Comparison
* Apparatus
* Sample Description
* Procedure
* Results
* Discussion
* Conclusions
* Future Plans

NHB 8060.1C (April 1991)

Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion.

Office of Safety and Mission Quality

Section 4.18 Arc Tracking (Test 18)

PURPOSE

* Determine ability of wire insulation materials and constructions to resist arc tracking.

* Assess damage caused by initial arcing and restrike events.

TEST CRITERIA:

NHB 8060.1C:

- Arc propagation on either initial application of power or on reapplication of power is considered a test failure.
- Tests conducted on samples of worst-case use insulation thickness and wire gauge, and in the worst-case environment.

Wiring for Space Applications Program:

- All candidate space application insulation constructions arc track.
- Worst case insulation: prepyrolized polyimide wire insulation.

Results of Arc Tracking Initiation.

* Self Extinguish (Best scenario).
  - No loss in wire bundle performance.
  - Charred insulation.
* Conductors Lose Insulation (exposed conductors)
  - Safety hazard.
  - Short-circuit risks
  - No loss in wire bundle performance.
* Severed Conductor.
  - Lost use of a wire pair within the bundle.
  - No loss in remainder of wire bundle performance.
  - No loss in wire bundle performance.
* Flashover Severs All Wires. (Worst scenario)

Best and Worst Case Differences

* Voltage difference between two conductors.
  - High enough to break down the dielectric strength of the charred material.
  - Not high enough to break down the dielectric strength of the charred material (self ext.)

* Current Flow:
  - High enough, such that Joule heating will continue to pyrolize neighboring insulation.
  - Not high enough, such that Joule heating will continue to pyrolize neighboring insulation.
    - Self Extinguish
    - Glow like a carbon filament light bulb (Vacuum case)

Properly Insulated Wire.

(Rated for task requirements)

- Will not Arc Track due to voltage difference between conductors.
- Will not Arc Track due to typical Joule heating from current in conductors.

Defectively Insulated Wire.

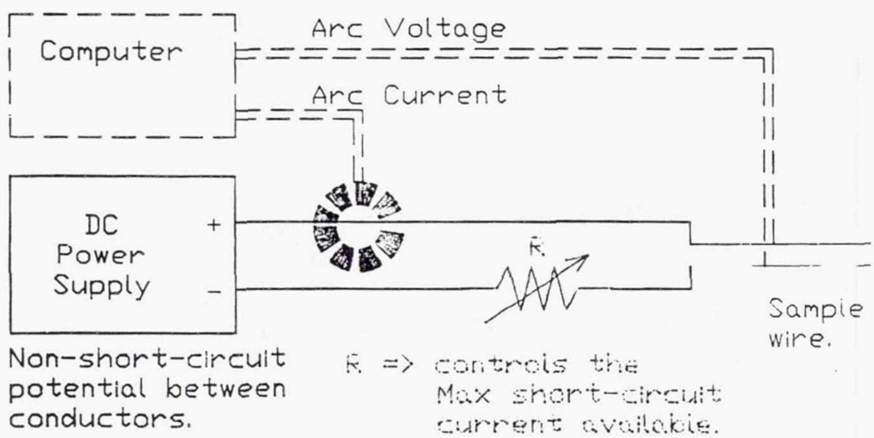
- May momentarily short-circuit
  - Arc generated heat may char the insulation.
  - Charred insulation lowers the dielectric strength.
- n # of momentary short-circuits before sustaining an arc.
- Worst state of insulation.
  - Pyrolized to the point of sustained arc tracking.
  - Restrike possible.
    dielectric strength.

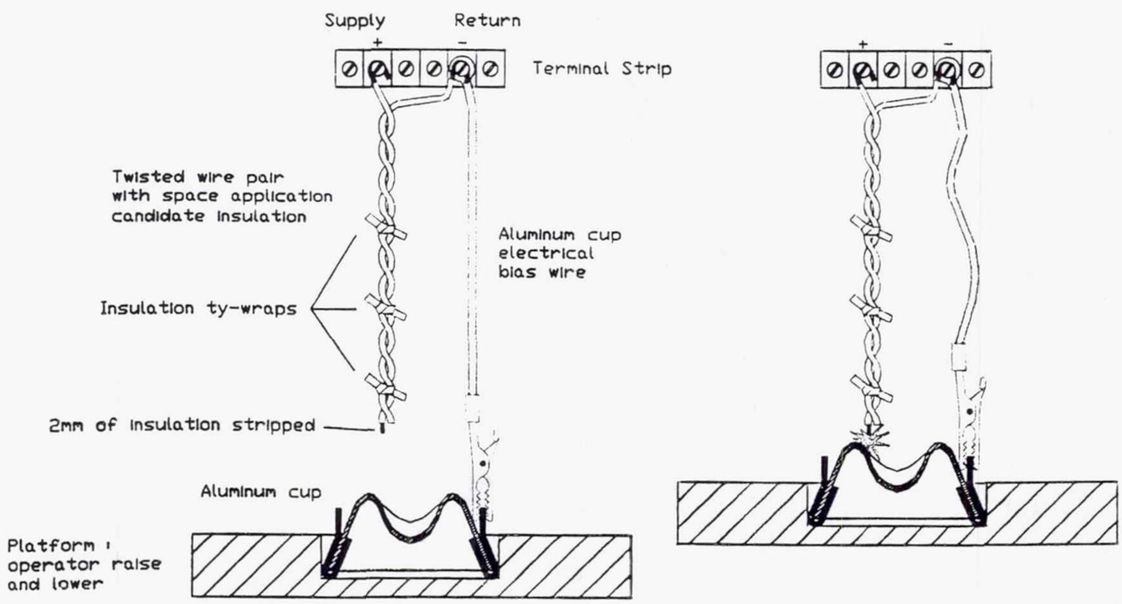
Necessary Restrike
Min. Voltage and Min Current

= EQUALS =

Min. Voltage and Min. Current
Necessary to Pyrolize the Insulation
To The Point of Sustained Arc Tracking

Arc Tracking Circuit.





Insulation Construction	Description
Champlain #1	2919 Kapton (50%OL)/Extruded XL ETFE
Filotex	PTFE Extrusion/616 Kapton (50% Min OL) /PTFE Dispersion.
Thermatics #3	Modified PTFE Tape (50% min OL)/TPT Tape (50% min OL)/Mod PTFE Tape (50% min OL)/PTFE Dispersion.

Abbreviations:

2919 Kapton	=>	0.5 mil Fluorocarbon (PTFE), 1 mil Polyimide, 0.5 mil Fluorocarbon (PTFE).
616 Kapton	=>	0.1 mil Fluorocarbon (FEP), 1 mil Polyimide, 0.1 mil Fluorocarbon (FEP).
XL	=>	Crosslinked.
ETFE	=>	Ethylene Tetrafluoroethylene.
OL	=>	Overlap.
PTFE	=>	Poly Tetrafluoroethylene.
1 mil	=>	25 micrometers.

PROCEDURE:

1) Sample Assembly and Installation.
2) Vacuum or Atmospheric Air Pressure.
3) Arc Tracking Initiation.
4) Arc Tracking Restrike.

ARC TRACKING INITIATION:

Objective: Manually initiate arc tracking on the wire sample.

Procedure: Raise and lower platform untill arc tracking started.

Next Step: Terminate power.
Reset power supplies to 0V.
Test samples ready for restrike tests.

ARC TRACKING RESTRIKE

Objective:	Ascertain minimum voltage to sustain an arc.
Procedure:	Increment voltage from 0.
Results:	Upon restrike, terminate arc by removing power.
Log Data:	Open-Circuit-Voltage, and employed current limiter.
Calculations:	Potential Short-Circuit-Current and, Volt * Amp product.

FUTURE INITIATION PLANS

Arc tracking did not initiate at onset of first momentary short-circuit.

Number of momentary arcs necessary to initiate arc tracking may be dependant on the intensity of the arc.

Quantify the energy necessary to initiate arc tracking by summing the energy in each arc during initiation exercises.

Use computer to log the data.

This information may determine which insulation type is least likely to start arc tracking.

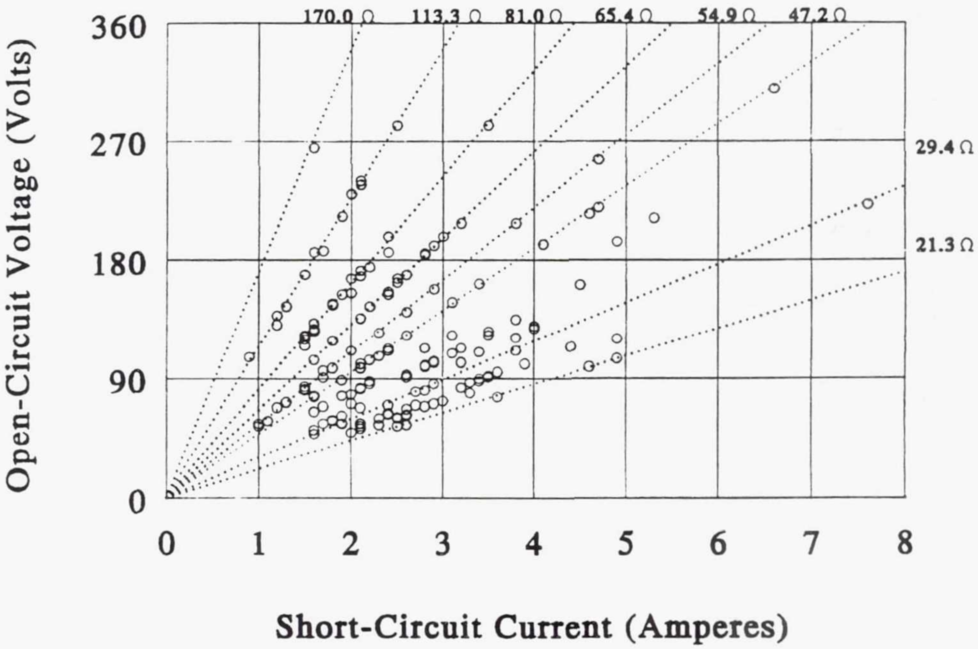
FUTURE RESTRIKE PLANS

Monitor voltage and current characteristics of an arc.

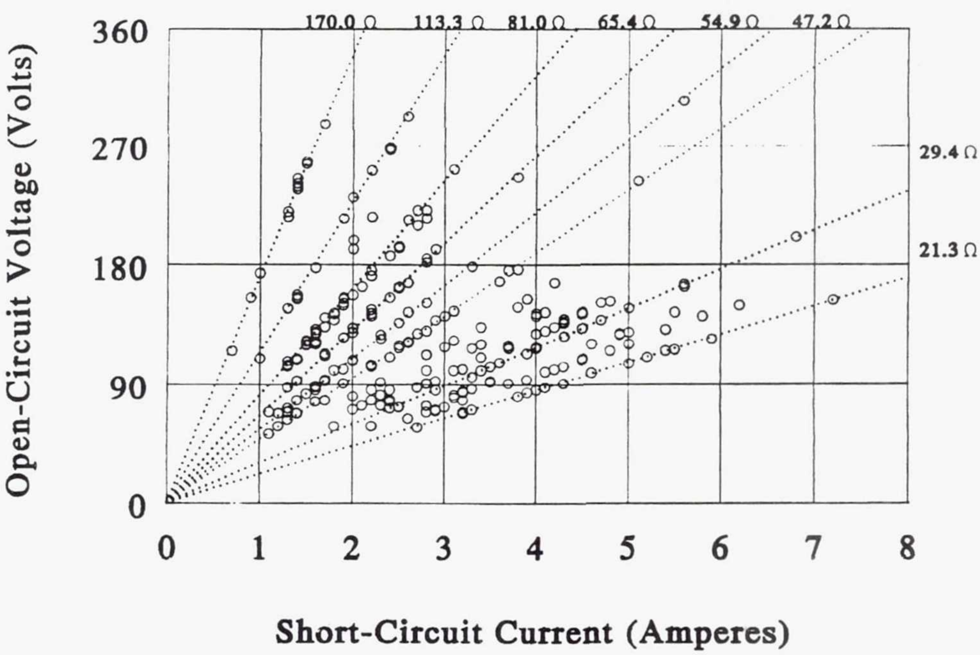
Obtain necessary pyrolysis energy.

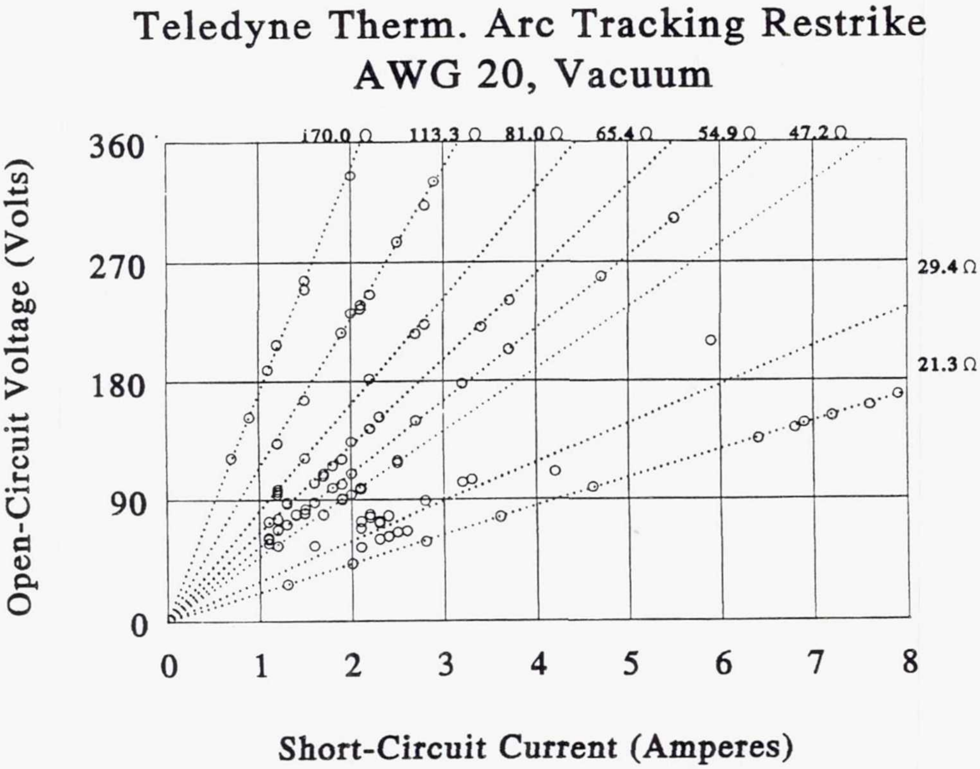
To determine which insulation type is least likely to restrike.

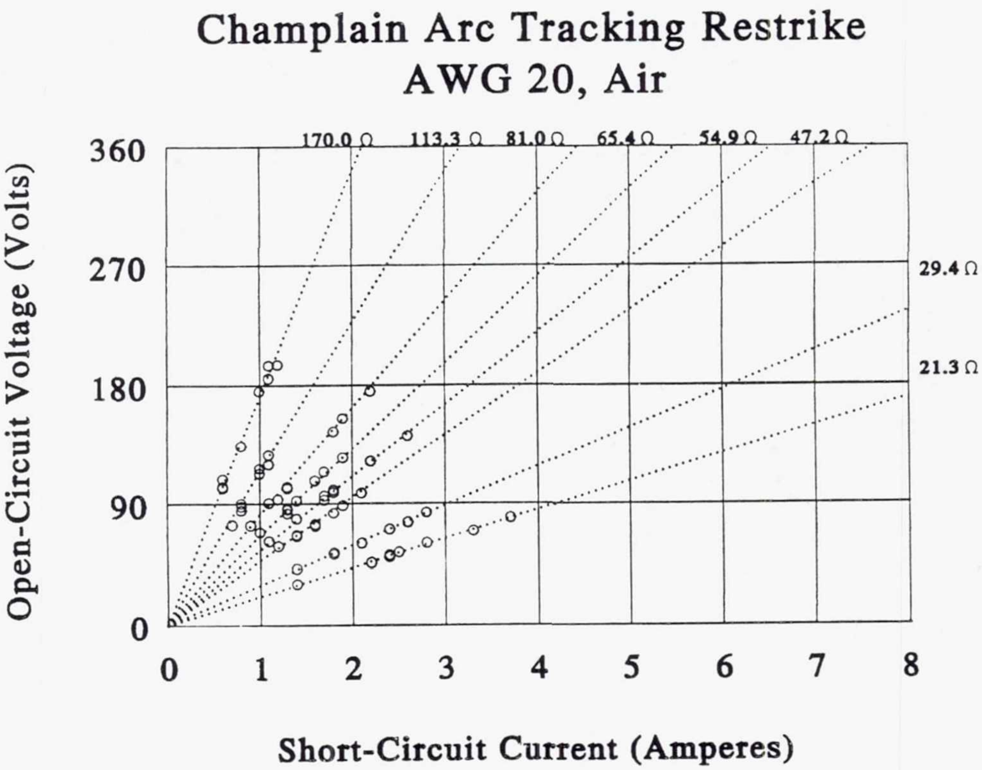
Champlain Arc Tracking Restrike
AWG 20, Vacuum

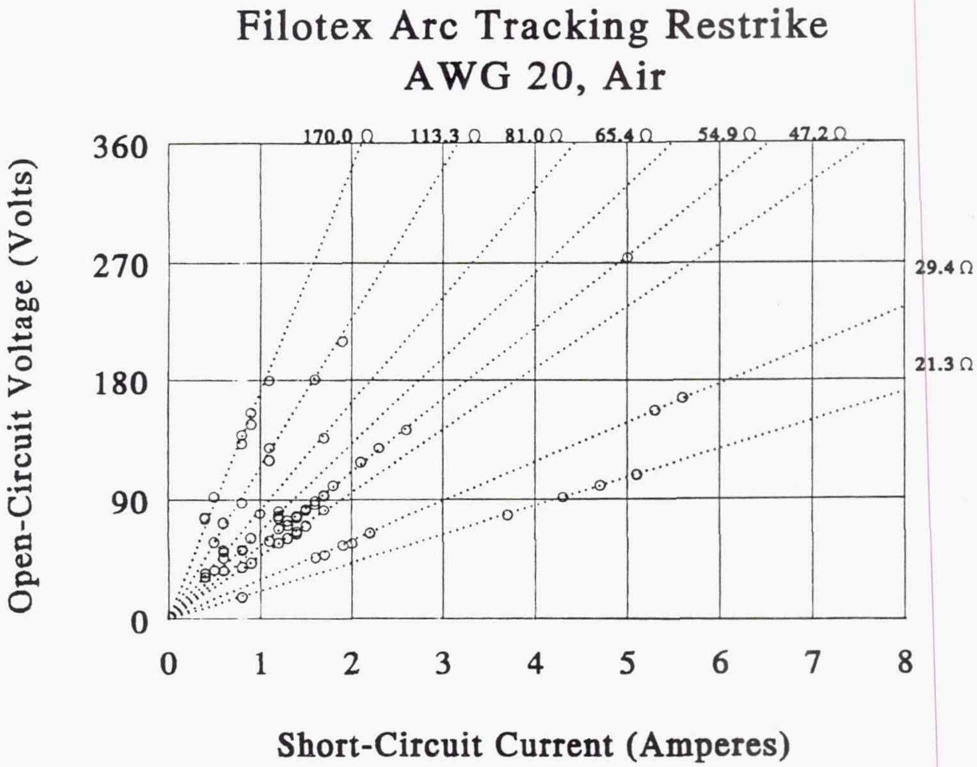


Filotex Arc Tracking Restrike
AWG 20, Vacuum




Teledyne Therm. Arc Tracking Restrike
AWG 20, Vacuum
170.0 Ω
113.3 Ω
81.0 Ω
65.4 Ω
54.9 Ω
47.2 Ω
29.4 Ω
21.3 Ω
Open-Circuit Voltage (Volts)
Short-Circuit Current (Amperes)
0
90
180
270
360
0
1
2
3
4
5
6
7
8


Champlain Arc Tracking Restrike
AWG 20, Air
170.0 Ω
113.3 Ω
81.0 Ω
65.4 Ω
54.9 Ω
47.2 Ω
29.4 Ω
21.3 Ω
Open-Circuit Voltage (Volts)
Short-Circuit Current (Amperes)
0
90
180
270
360
0
1
2
3
4
5
6
7
8


Filotex Arc Tracking Restrike
AWG 20, Air
Open-Circuit Voltage (Volts)
Short-Circuit Current (Amperes)
170.0 Ω
113.3 Ω
81.0 Ω
65.4 Ω
54.9 Ω
47.2 Ω
29.4 Ω
21.3 Ω
0
90
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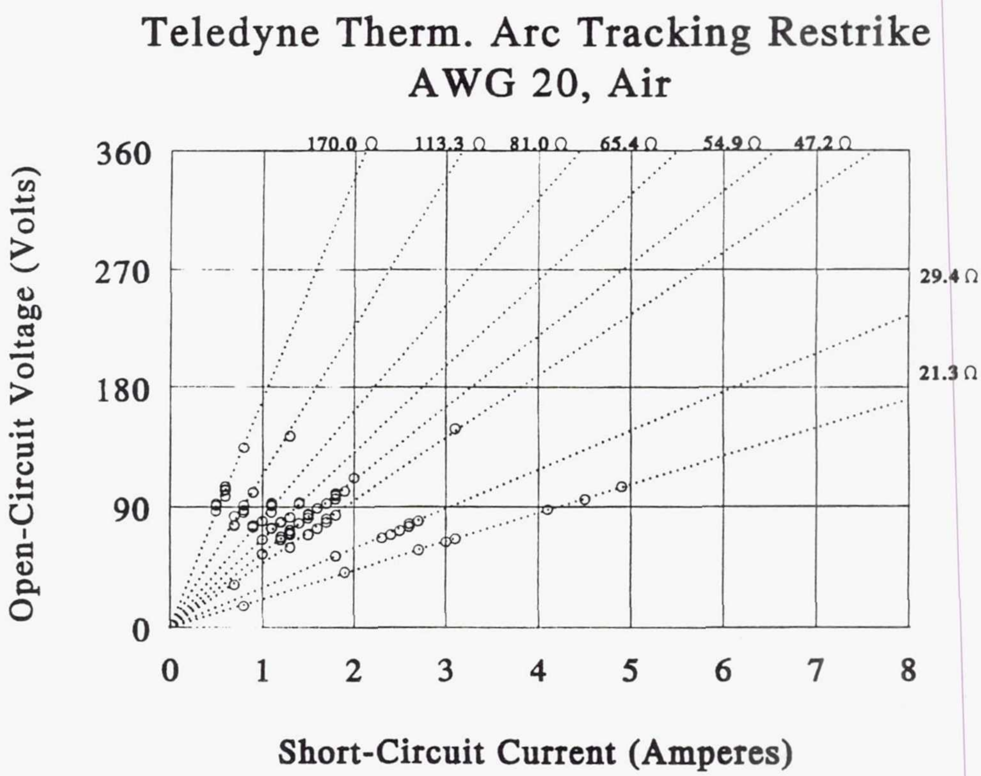
Teledyne Therm. Arc Tracking Restrike
AWG 20, Air
Open-Circuit Voltage (Volts)
Short-Circuit Current (Amperes)
170.0 Ω
113.3 Ω
81.0 Ω
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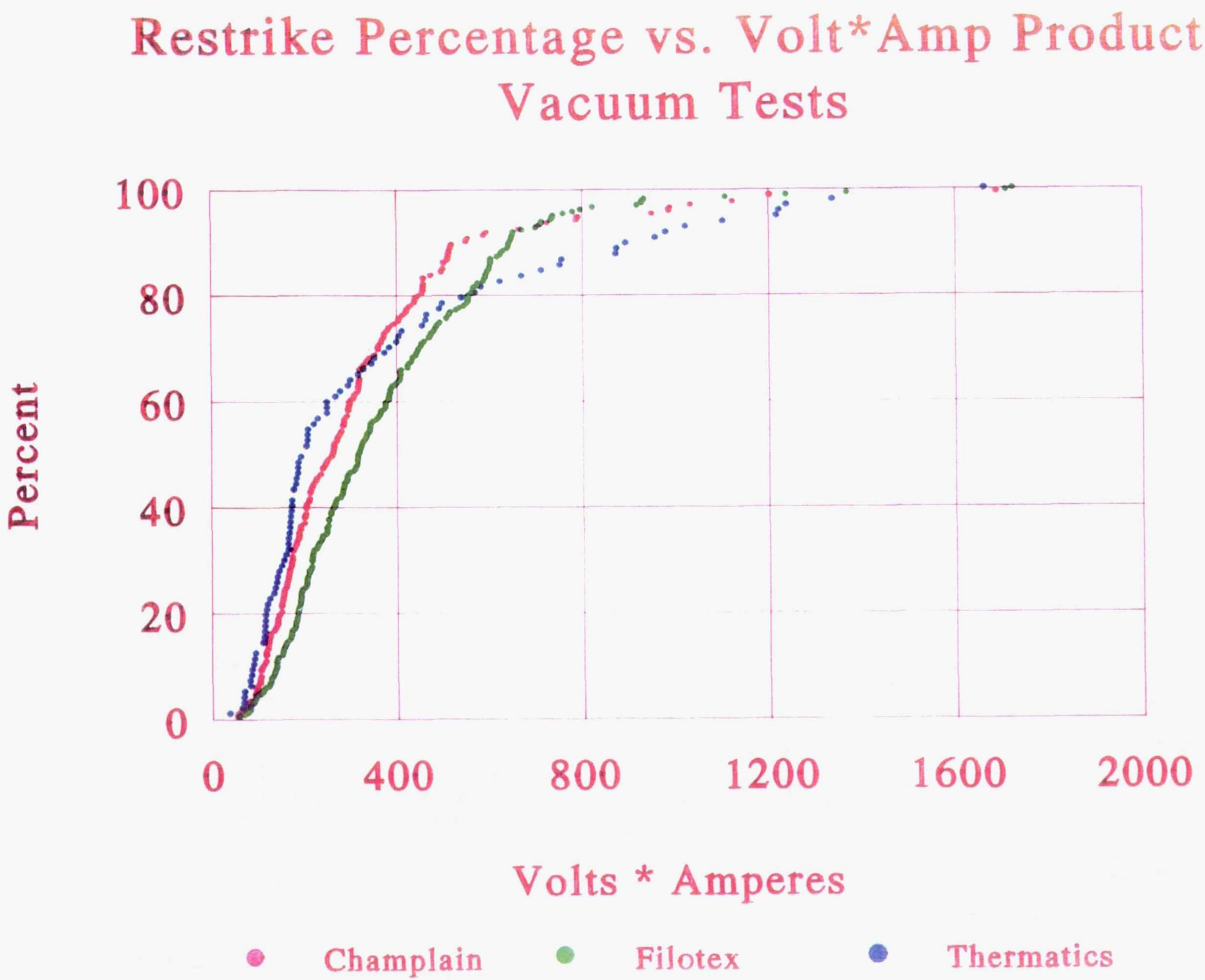

Restrike Percentage vs. Volt*Amp Product
Vacuum Tests
100
80
60
40
20
0
Percent
0
400
800
1200
1600
2000
Volts * Amperes
Champlain
Filotex
Thermatics

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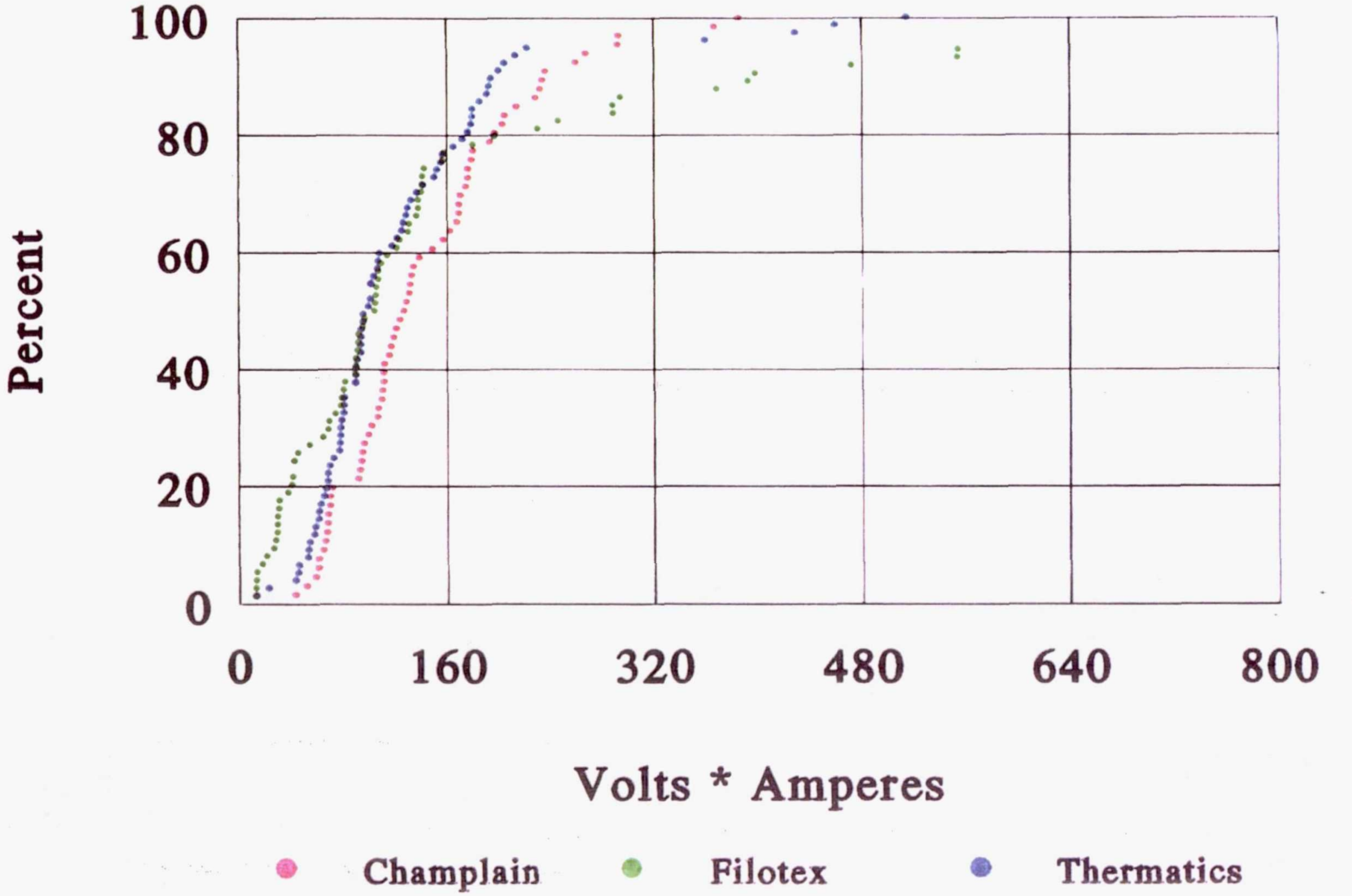
Restrike Percentage vs. Volt*Amp Product
Air Tests



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DISCUSSION

* Remnants of hexagonal, graphitic carbon residue remained.
* Carbon residue, not necessarily a perfect conductor (gaps).
* Gaps prevent current flow, for low voltage.
* Higher electric field strengths may exceed carbon/gap median dielectric strength.
* Necessary breakdown voltage may be dependant on carbon trace positioning.
* Joule heating results from an arc breakdown.
* Restrike data describes breakdown voltage and necessary available current for Joule heating.

CONCLUSIONS

- Arc tracking tests conducted on Champlain, Filotex, and Teledyne Thermatics indicate the Filotex is least likely to arc track.
- Arc tracking occurs more readily in air than it does in vacuum.

PLANNED ACTIVITIES

- Further testing will be conducted to consider other space application candidate wire insulation constructions.
- Future testing will be done to determine ambient temperature influence on arc tracking
- Future testing will be conducted to determine the level of Joule heating necessary for arc tracking initiation and propagation.

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WIRE INSULATION DEGRADATION AND FLAMMABILITY IN LOW GRAVITY

Robert Friedman
NASA Lewis Research Center
Cleveland, Ohio

WIRE INSULATION DEGRADATION AND FLAMMABILITY IN LOW GRAVITY

ORGANIZATION OF PRESENTATION

- INTRODUCTION TO SPACECRAFT FIRE SAFETY
- CONCERNS IN FIRE PREVENTION IN LOW GRAVITY
- SHUTTLE WIRE INSULATION FLAMMABILITY EXPERIMENT
- DROP TOWER RISK-BASED FIRE SAFETY EXPERIMENT
- EXPERIMENT RESULTS, CONCLUSIONS AND PROPOSED STUDIES

SPACECRAFT FIRE-SAFETY CHALLENGES

FIRE SAFETY ALWAYS RECEIVES PRIORITY ATTENTION IN NASA MISSION DESIGNS AND OPERATIONS—THE PRIMARY APPROACH IS THROUGH FIRE PREVENTION.

CONVENTIONAL FIRE-SAFETY TECHNIQUES ARE DIFFICULT TO APPLY TO SPACECRAFT, HOWEVER.

- THE SPACECRAFT INTERIOR IS A CONFINED ENVIRONMENT, WITH LIMITED RESOURCES AND ALMOST NO ESCAPE POTENTIAL.
- THERE IS LITTLE PAST EXPERIENCE TO FURNISH ACCURATE RISK PREDICTIONS FOR DESIGN OF SAFETY SYSTEMS.
- THE EXTREME HIGH VALUE OF SPACECRAFT AND MISSION OPERATIONS OFFERS NO OPTIONS OR SACRIFICES.
- THE LACK OF NATURAL CONVECTIVE STRONGLY INFLUENCES FIRE CHARACTERISTICS.

INFLUENCE OF LOW GRAVITY ON FIRES

BUOYANCY (UP) AND SEDIMENTATION (DOWN) FLOWS ARE GREATLY DIMINISHED, AFFECTING

MASS TRANSFER OF FUEL AND OXYGEN

HEAT TRANSFER TO AND FROM FLAME ZONE

FLAME CHARACTERISTICS OF TEMPERATURE, COMBUSTION PRODUCTS, AND SO ON

FIRES IN SPACE ARE NOT NECESSARILY "BETTER" OR "WORSE" BUT THEY ARE CERTAINLY "DIFFERENT"

WIRE-INSULATION BREAKDOWNS AND FIRE SAFETY

- BECAUSE OF THE LACK OF CONVECTIVE COOLING IN MICROGRAVITY, SURFACE TEMPERATURES RESULTING FROM BREAKDOWNS (OVERLOADS, ARC TRACKING) CAN EXCEED THOSE IN NORMAL GRAVITY.
- CONSEQUENTLY, IF NO REMEDIAL ACTION IS TAKEN, BREAKDOWNS MAY LEAD TO IGNITIONS AND FIRE SPREAD IN THE PRESSURIZED SPACECRAFT ATMOSPHERE.
- SHUTTLE MISSIONS HAVE EXPERIENCED A BREAKDOWN ON THE AVERAGE OF ONCE EACH 1600 HOURS OF OPERATION.
- NO IGNITION HAS RESULTED FROM THE SHUTTLE BREAKDOWNS, DUE TO THE MATERIAL CONTROLS AND THE IMMEDIATE RESPONSE OF THE CREW.
- THE SPACE STATION MAY HAVE A MORE SEVERE SAFETY PROBLEM IF BREAKDOWNS OCCUR DURING UNTENDED PERIODS.

SHUTTLE "BREAKDOWN" EXPERIENCE

FIVE REPORTED ELECTRICAL EVENTS

APRIL 1983	WIRES OVERHEATED AND FUSED AT MATERIAL PROCESSING UNIT
AUG. 1989	SHORT CIRCUIT FROM CABLE STRAIN AND INSULATION SPLIT AT TELEPRINTER
DEC. 1990	RESISTOR OVERHEATED FROM COOLING FAN FAILURE IN ELAPSED-TIME CIRCUIT OF DIGITAL DISPLAY UNIT
JUNE 1991	REFRIGERATOR-FREEZER FAN MOTOR FAILURE DUE TO COOLING FLOW LOSS
JULY 1992	BLOWN ELECTRICAL CAPACITOR IN MEDICAL APPARATUS

SIX REPORTED INTERMITTENT OR CONTINUOUS FALSE ALARMS

FIVE REPORTED FAILURES OF SMOKE DETECTOR SELF-TEST CONFIRMATIONS

NASA LEWIS
MICROGRAVITY WIRE-INSULATION FLAMMABILITY EXPERIMENTS

WIRE INSULATION FLAMMABILITY (NASA LEWIS, NIST):

SHUTTLE STS-50 GLOVEBOX, JUNE 1992

- LONG-TERM OBSERVATIONS OF MICROGRAVITY FLAMMABILITY AND FLAME SPREAD OVER HEATED WIRES WITH PROMOTED IGNITION AND AIR FLOW OPPOSED TO AND CONCURRENT WITH THE FLAME SPREAD

RISK-BASED FIRE SAFETY EXPERIMENT (UCLA):

NASA LEWIS 2-SEC DROP TOWER, SEPT. TO DEC. 1992

- VERY SHORT-TERM OBSERVATIONS OF MICROGRAVITY DEGRADATION AND IGNITION OF SELF-HEATED WIRES UNDER QUIESCENT CONDITIONS

WIRE-INSULATION BREAKDOWN EXPERIMENT (NASA)

NASA LEWIS AIRPLANE, PROPOSED

- 20-SEC OBSERVATIONS OF LOW-GRAVITY ARC-TRACKING AND IGNITIONS OF SELF-HEATED AND SHORTED WIRES WITH AIR FLOW AND ATMOSPHERIC OXYGEN AND PRESSURE VARIATIONS

WIRE INSULATION FLAMMABILITY EXPERIMENT

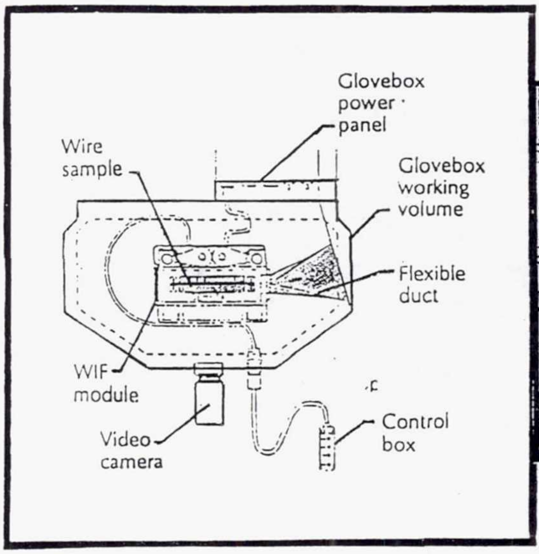
USML-1 GLOVEBOX ON SHUTTLE STS-50, JUNE 1992

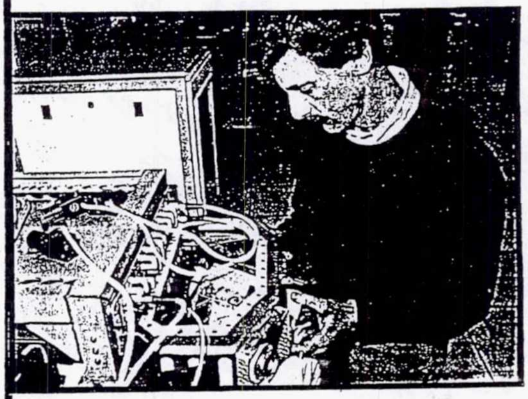
OBJECTIVES:
- FLAMMABILITY AND FLAME-SPREAD RATES OF WIRE INSULATION IN QUIESCENT MICROGRAVITY ENVIRONMENT
- EFFECTS OF CONTROLLED AIR FLOW ON ABOVE
- TRANSIENT HEATING AND OFFGASSING BEHAVIOR IN MICROGRAVITY

APPARATUS:
- FOUR SEPARATE TEST MODULES WITH ONE SAMPLE EACH FOR TESTS AT FOUR CONDITIONS OF HEAT LEVELS AND AIR FLOWS OPPOSED AND CONCURRENT TO FLAME SPREAD

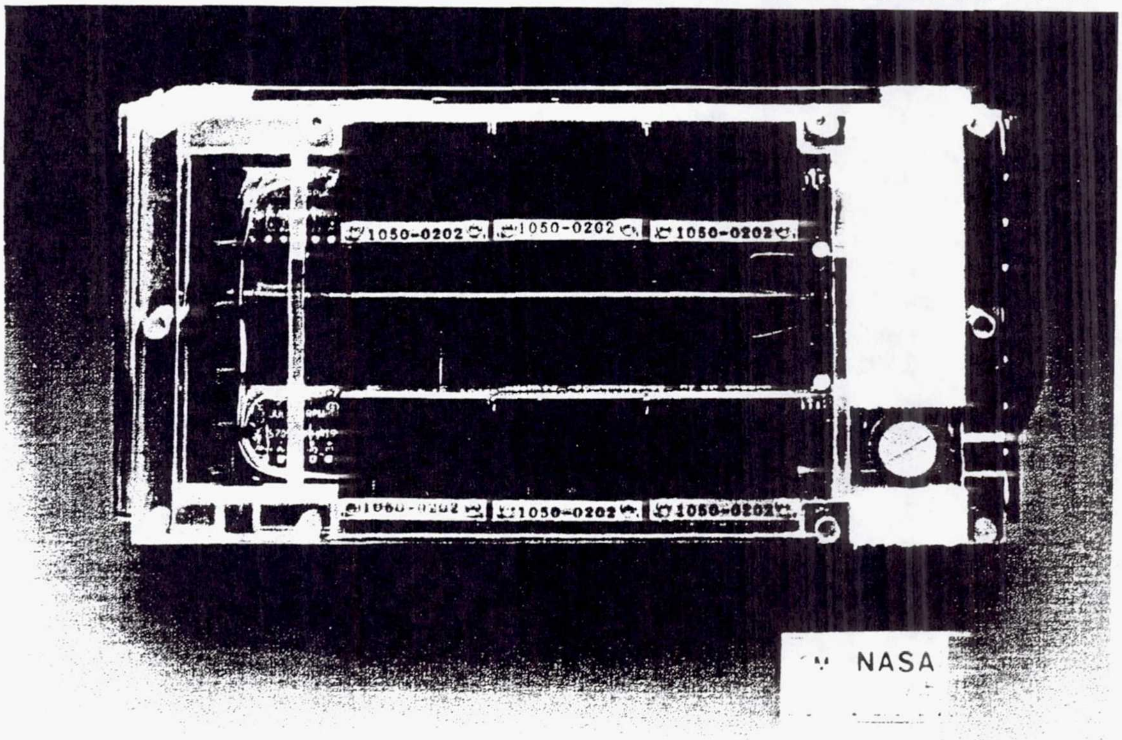
APPROACH:
- POLYETHYLENE-INSULATED NICHROME WIRE IS HEATED BY ELECTRIC CURRENT, THEN IGNITED BY EXTERNAL HOT WIRE IGNITER AT ONE END OF WIRE

GLOVEBOX WIRE INSULATION FLAMMABILITY EXPERIMENT (WIF) MODULE

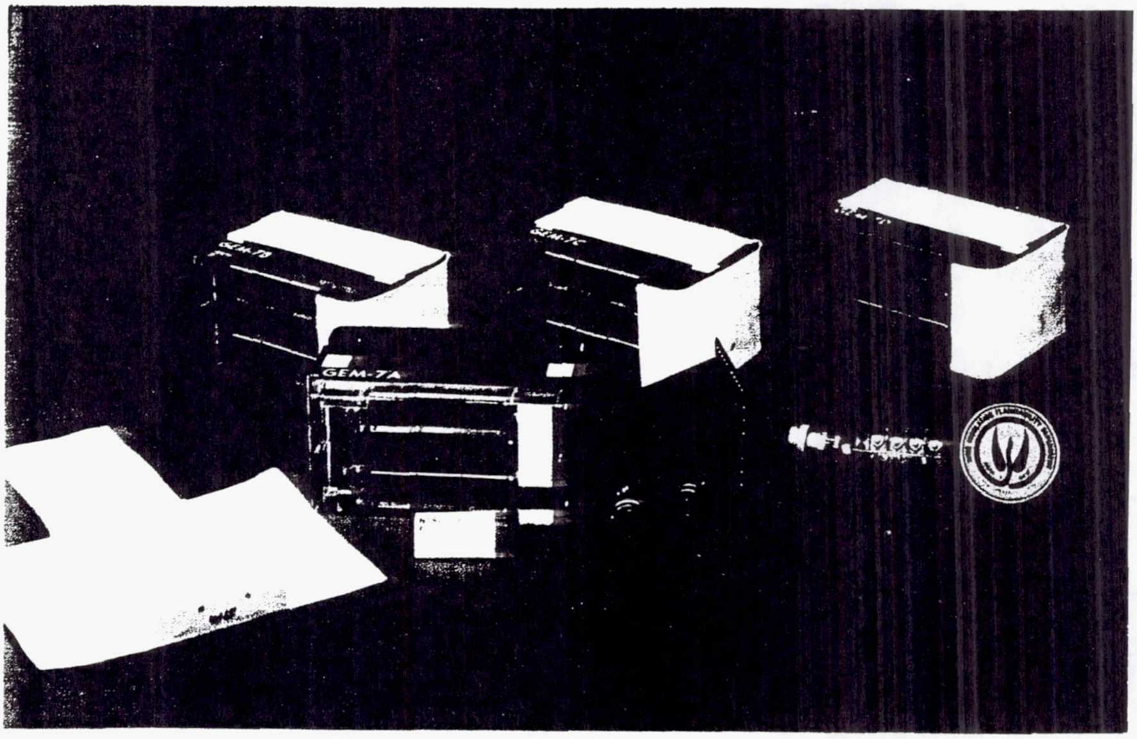




WIRE INSULATION FLAMMABILITY EXPERIMENT - MODULE FRONT VIEW



WIRE INSULATION FLAMMABILITY EXPERIMENT
SET OF FOUR MODULES



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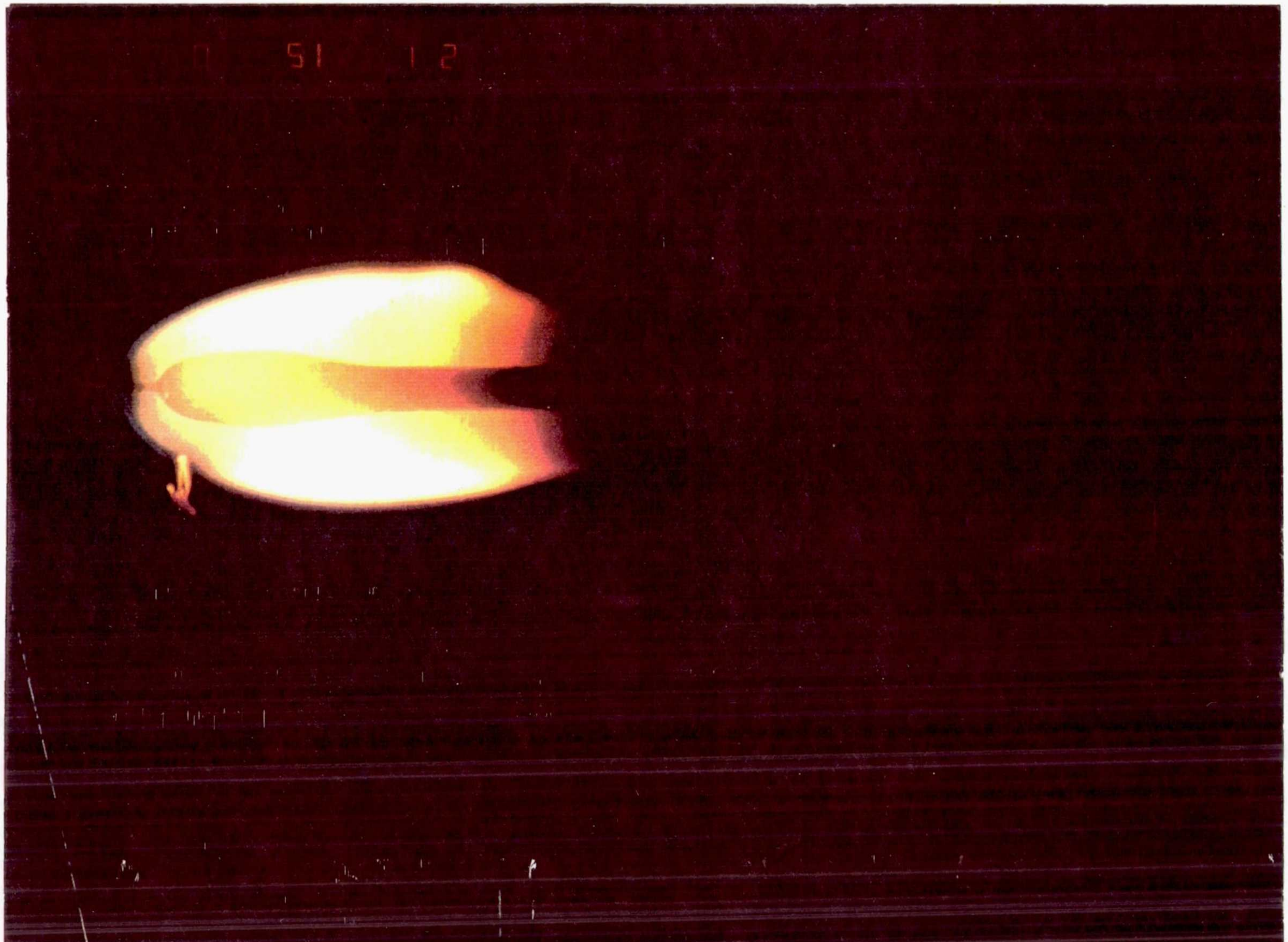
WIRE INSULATION FLAMMABILITY EXPERIMENT
FLAME PROGRESSING FROM LEFT TO RIGHT - CONCURRENT AIR FLOW



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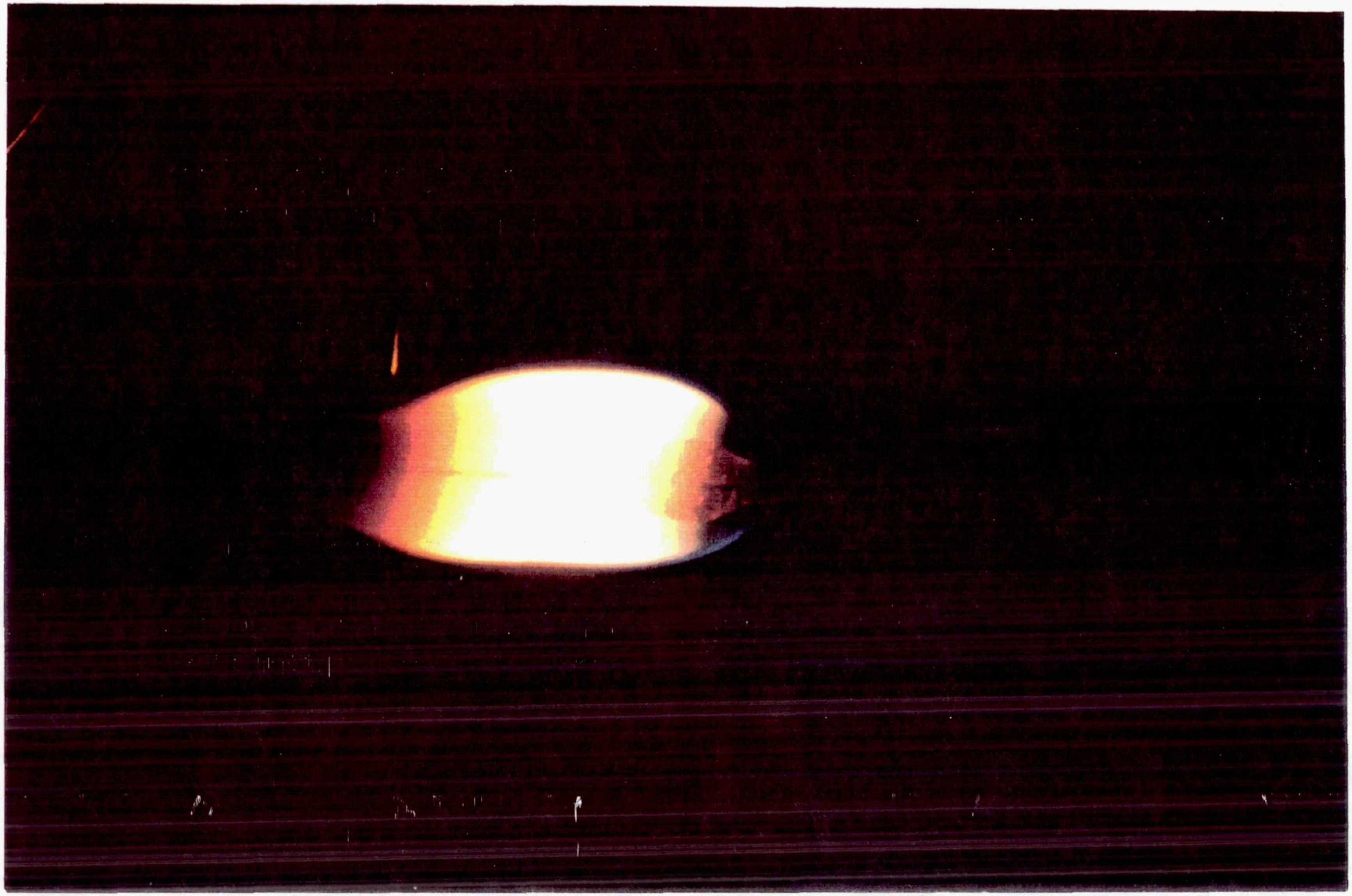
WIRE INSULATION FLAMMABILITY EXPERIMENT
FLAME PROGRESSING FROM LEFT TO RIGHT - OPPOSED AIR FLOW



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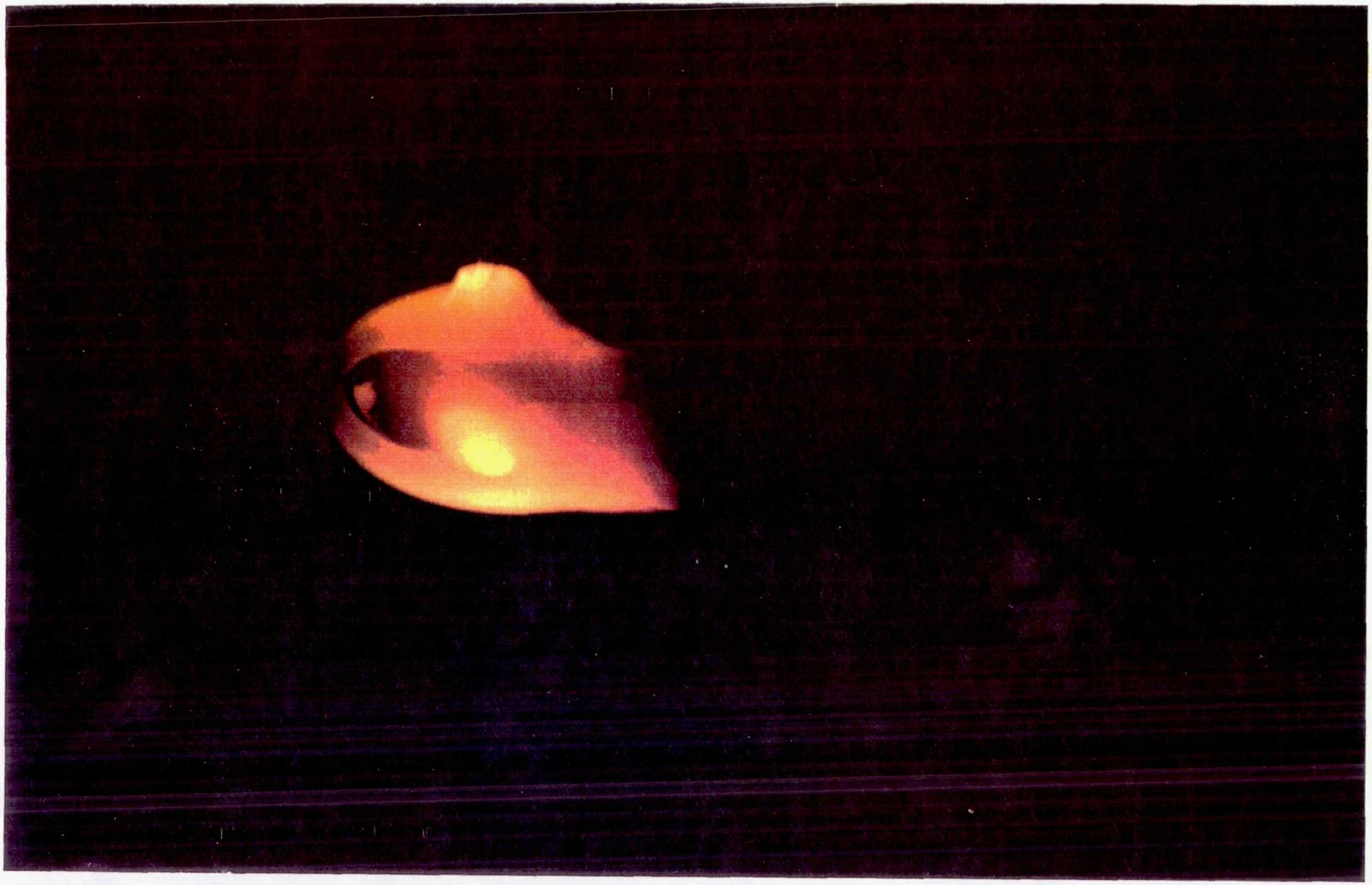
WIRE INSULATION FLAMM. EXPER. - CONCURRENT AIR FLOW



NOTE →ASYMMETRIC INSULATION DROPLET →GLOBULE EXPULSION

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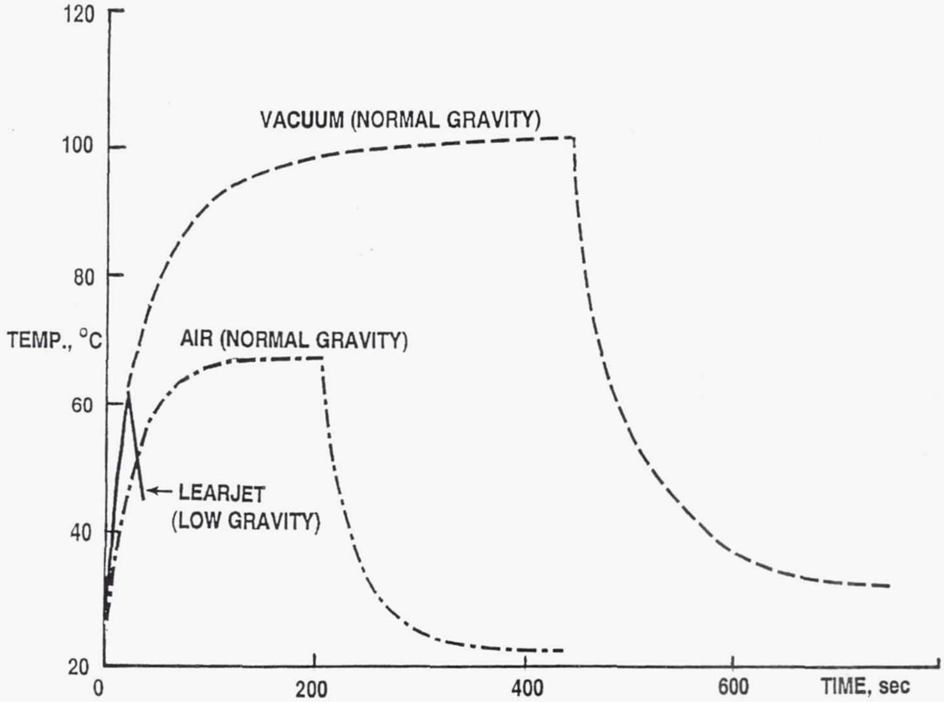
WIRE INSULATION FLAMMABILITY EXPERIMENT
SELECTED WIRE TEMPERATURE HISTORIES



WIRE INSULATION FLAMMABILITY EXPERIMENT

RESULTS AND CONCLUSIONS

BEHAVIOR IN MICROGRAVITY COMPARED TO NORMAL GRAVITY

- TRANSIENT HEATING RATES AND MAXIMUM WIRE TEMPERATURES ARE HIGHER THAN IN (NORMAL-GRAVITY) AIR BUT COMPARABLE TO THOSE UNDER VACUUM.
- FLAME-SPREAD RATE IS STRONGLY AFFECTED BY THE FORCED AIR FLOW. RATES ARE HIGHER FOR CONCURRENT FLOW THAN FOR OPPOSED FLOW. IN FACT, STEADY STATE WAS NEVER ACHIEVED IN CONCURRENT FLOW.
- MOLTEN FUEL FORMS SPHERICAL DROPS ADHERING TO WIRE.
- FUEL VAPORS FROM OVERHEATED WIRE CAN ACCUMULATE AND IGNITE.
- MEAN SOOT PARTICLE SIZE IS GREATER BY FACTOR OF 2 FOR CONCURRENT FLOW, BY 3 FOR OPPOSED FLOW; SIZE RANGE IS ALSO GREATER.

UCLA RISK-BASED FIRE-SAFETY EXPERIMENT

NASA LEWIS 2-sec DROP TOWER, SEPT.-DEC. 1992

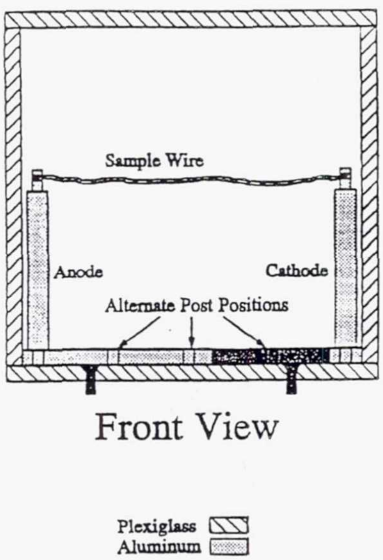
OBJECTIVES:
- QUANTITATIVE RISK ASSESSMENTS OF FIRE PROBABILITIES AND CONSEQUENCES IN ADVANCED SPACECRAFT
- SMALL-SCALE FIRE EXPERIMENTS TO FURNISH CHARACTERISTICS AND TIME CONSTANTS FOR ANALYSES
- EVENTUAL SPACE EXPERIMENT IN GASCAN

APPARATUS:
- CHAMBER WITH WIRE SAMPLE MOUNTED IN FRAME FOR DROP TESTING IN FREE-FALL MICROGRAVITY

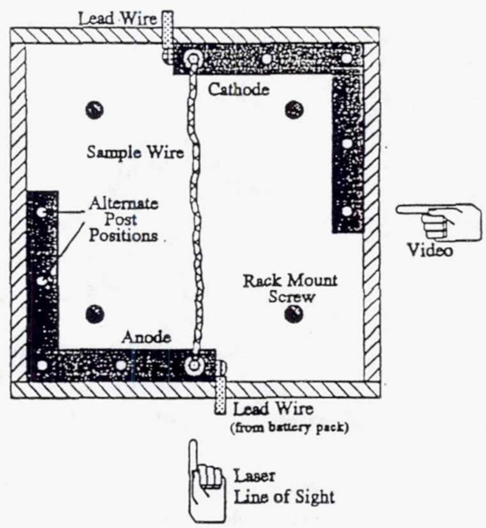
APPROACH:
- TEFLON, TEFZEL (FLUORINATED ETHYLENE-PROPYLENE), AND KAPTON (POLYIMIDE)-INSULATED COPPER WIRES ARE OVERHEATED TO DEGRADATION OR IGNITION, TO REPRESENT A PROBABLE SPACECRAFT BREAKDOWN INCIDENT

APPARATUS FOR HEATED-WIRE SCENARIO VALIDATION

MICROGRAVITY TEST SERIES AT LeRC

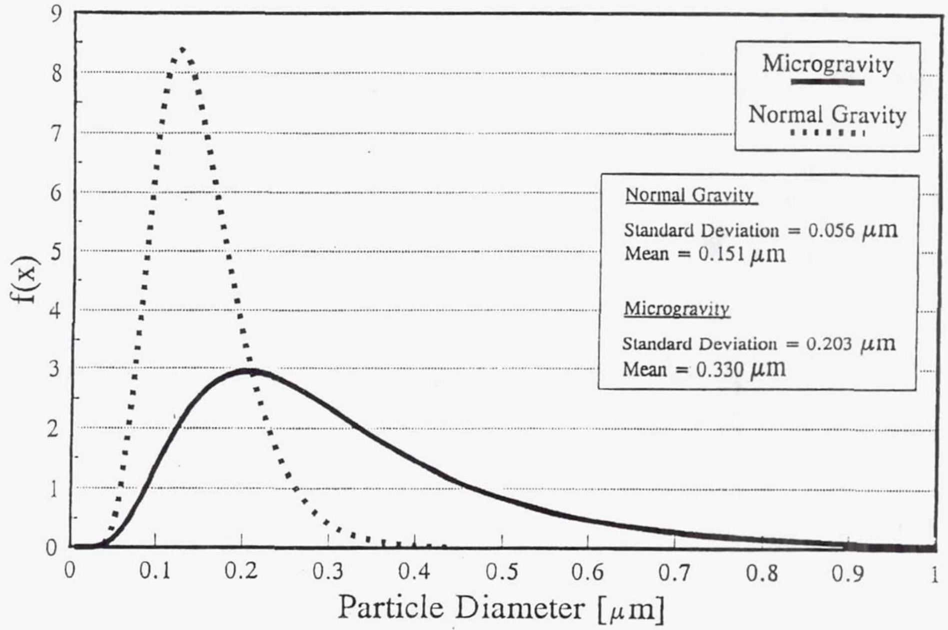


Front View

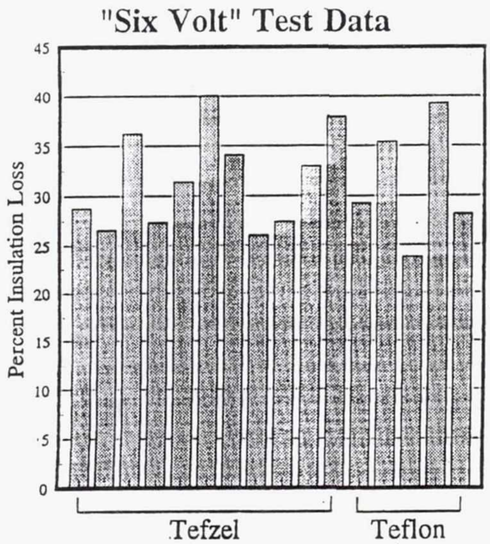


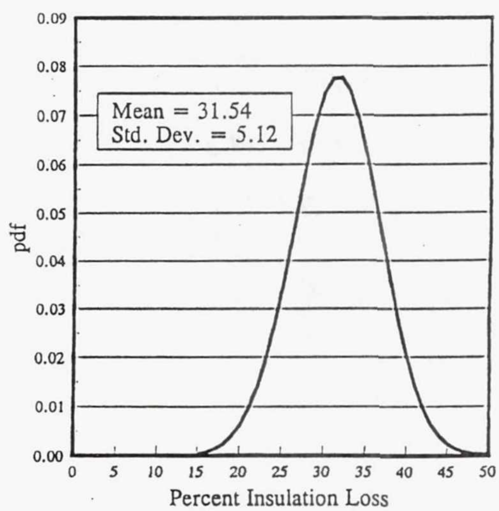
Plan View

LOG-NORMAL CURVE FIT FOR PARTICLE DIAMETERS

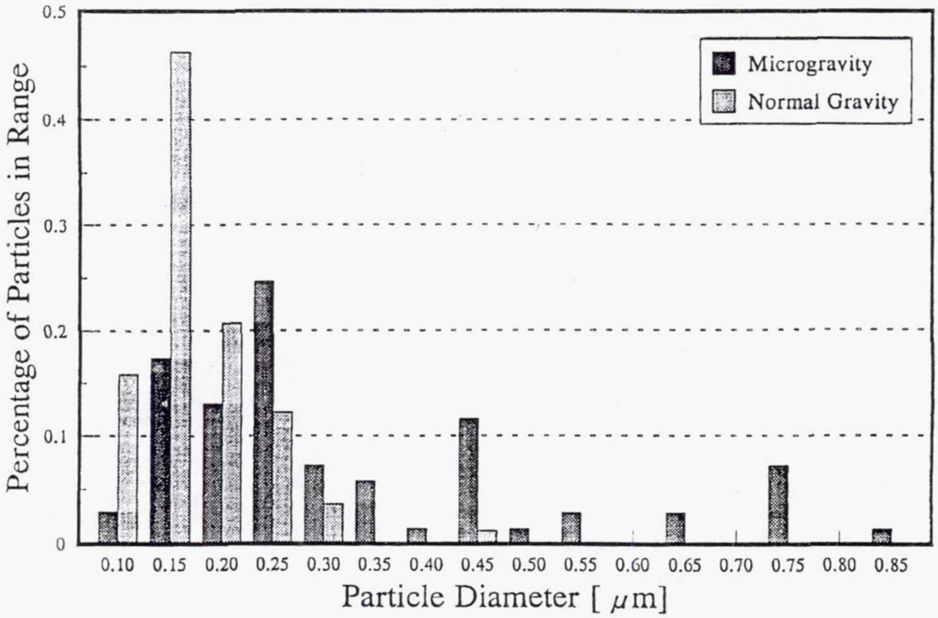


GROUND-BASED TEST RESULTS ON INSULATION MASS LOSS





PARTICLE DIAMETER HISTOGRAM



UCLA RISK-BASED FIRE-SAFETY EXPERIMENT

RESULTS AND CONCLUSIONS

BEHAVIOR IN MICROGRAVITY COMPARED TO NORMAL GRAVITY

- KAPTON AND TEFZEL INSULATION (CONSIDERED NON-FLAMMABLE IN NORMAL GRAVITY) FLAMED IN SOME INSTANCES.
- DAMAGE TO WIRE INSULATION IS MORE SEVERE.
- MASS CONSUMPTION RATE OF BURNING INSULATION IS GREATER; HENCE, MORE SMOKE AND GASES ARE PRODUCED.
- MEAN SMOKE PARTICLE SIZE IS GREATER BY FACTOR OF 2.
- SMOKE-PARTICLE SIZE DISTRIBUTION IS WIDER (GREATER STANDARD DEVIATION).

WIRE-INSULATION BREAKDOWN EXPERIMENT

PROPOSED FOR NASA LEWIS LOW-GRAVITY AIRPLANE FACILITY

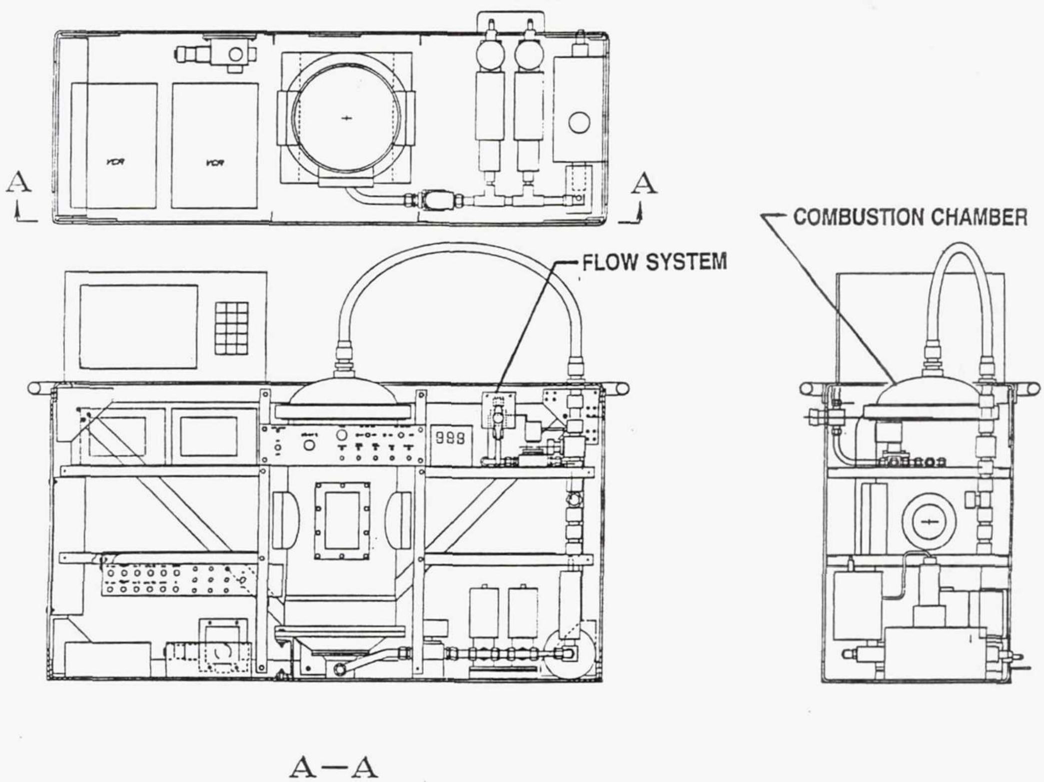
OBJECTIVES:
- ARC-TRACKING, DEGRADATION, AND IGNITION SUSCEPTIBILITY OF CURRENT AND ADVANCED WIRES INSULATIONS IN A LOW-GRAVITY ENVIRONMENT
- EFFECTS OF CONTROLLED AIR FLOW ON ABOVE
- EFFECTS OF ATMOSPHERIC PRESSURE AND OXYGEN

APPARATUS:
- TEST CHAMBER, FLOW SYSTEM, AND DIAGNOSTICS EXISTING; TEST FIXTURE AND EXPERIMENT PLAN TO BE DEVISED

APPROACH:
- STILL UNDER DISCUSSION

IN ADDITION TO THE PROPOSED AIRPLANE ACCOMMODATION, THIS EXPERIMENT IS AN EXCELLENT CANDIDATE FOR A SHUTTLE GLOVEBOX PROJECT.

LOW-GRAVITY AIRPLANE FIRE SAFETY FACILITY PROPOSED FOR WIRE-INSULATION BREAKDOWN EXPERIMENT



CONCLUSIONS

- THERE IS A FINITE PROBABILITY OF A BREAKDOWN (ARC TRACKING, FOR EXAMPLE) OCCURRING IN SPACECRAFT (ABOUT ONCE IN 1600 MISSION HOURS).
- THE LACK OF CONVECTIVE COOLING CAN LEAD TO HIGHER SURFACE TEMPERATURES FOLLOWING BREAKDOWNS. IN THE PRESSURIZED SPACECRAFT CABIN, THIS OVERHEATING CAN INCREASE THE PROBABILITY OF IGNITIONS.
- THE RELATIVE RANKING OF MATERIAL RESISTANCE TO DEGRADATION, OFF-GASSING, OR IGNITION MAY BE DIFFERENT IN MICROGRAVITY COMPARED TO NORMAL GRAVITY.
- THE AUTOMATED DETECTION OF SMOLDERING, DEGRADATION, OR OTHER BREAKDOWN "SIGNATURES" IN SPACECRAFT IS VERY DIFFICULT.
- ADDITIONAL EXPERIMENTAL DATA AND ANALYSES ARE CRITICALLY NEEDED TO SUPPORT RISK ASSESSMENTS, MATERIAL ACCEPTANCE STANDARDS, FIRE DETECTION, AND FIRE SUPPRESSION IN SPACECRAFT.

BREAKDOWN TESTING OF WIRING INSULATION

J.R. Laghari
State University of New York at Buffalo
Buffalo, New York

BACKGROUND

M81381 (Polyimide) is widely used for wiring insulation in aerospace applications

Advantages

- Light Weight
- High Service Temperature
- High Breakdown Strength
- Availability

Disadvantages

- Resistive Heating
- Lossy at High Temperature
- Absorbs Moisture
- Arc Tracking
- Fire Hazard

TYPICAL OPERATING VOLTAGES

- 28 Volts dc (Space Shuttle)
- 120 Volts dc

  (Currently Proposed for Space Station Freedom)
- 28-270 Volts dc

  (Expendable Launch Vehicles)
- 115 V 3-ph 400 Hz (Aerospace Applications)

TASK

To evaluate dielectric strength at high temperature of potential wiring insulation recommended by NASA LeRC to replace existing M81381 (Polyimide)

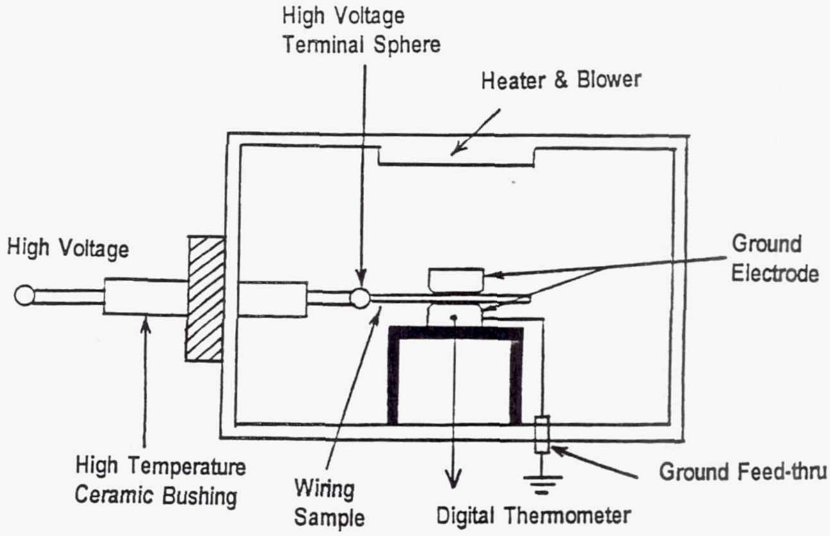
Top Candidates Recommended by NASA LeRC for Dielectric Testing at UB

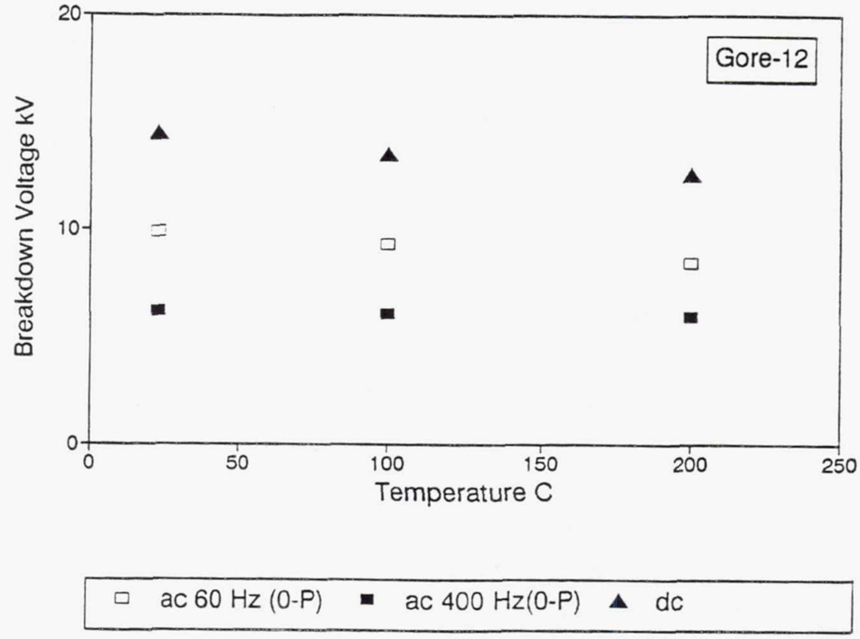
Gore	12 AWG
Gore	20 AWG
Tensolite	12 AWG
Tensolite	20 AWG
Filotex	12 AWG
Filotex	20 AWG
Kapton (M81381)	12 AWG
Kapton (M81381)	20 AWG
Teledyne	12 AWG
Teledyne	20 AWG
Barcel	20 AWG
Champlain	20 AWG

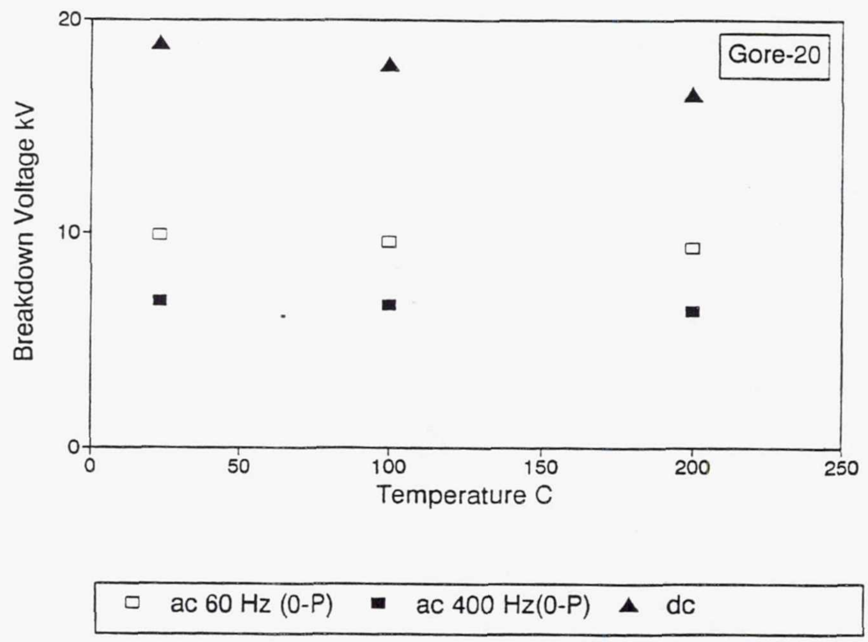
Wiring Cable Specifications

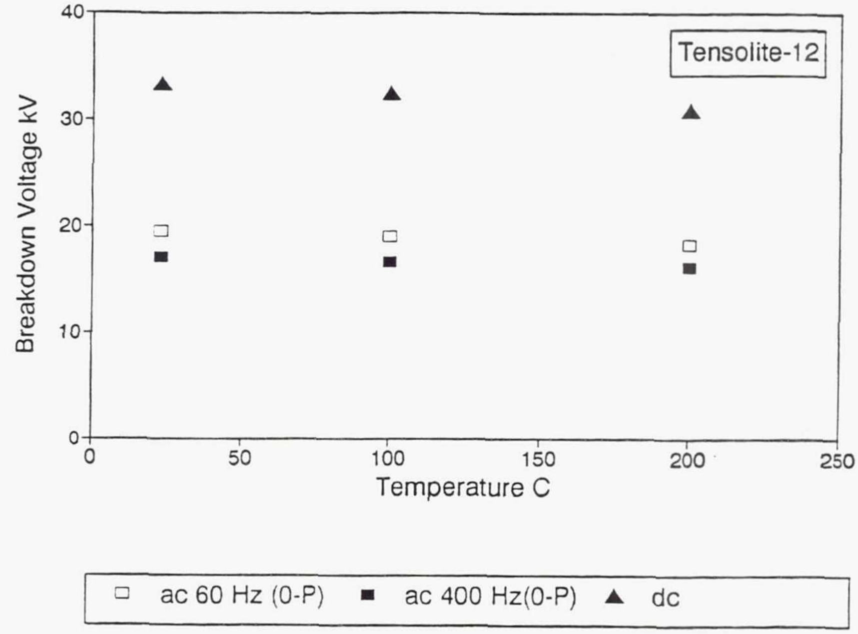
Sample	Insulation System	Insulation Thickness
Gore-12	PTFE/ High Strength PTFE/ PTFE	6 mil
Gore-20	PTFE/ High Strength PTFE/ PTFE	6 mil
Tensolite-12	PTFE/ Polyimide/ PTFE	7.15 mil
Tensolite -20	PTFE/ Polyimide/ PTFE	6.15 mil
Filotex -12	PTFE/ Polyimide/ FEP	6.9 mil
Filotex -20	PTFE/ Polyimide/ FEP	6.5 mil
M81381-12	Kapton with Polyimide top coat	8.6 mil
M81381-20	Kapton with Polyimide top coat	8.6 mil
Teledyne-12	PTFE/ Polyimide/ PTFE	~ 6 mil
Teledyne-20	PTFE/ Polyimide/ PTFE	~ 6 mil
Barcel-20	Kapton/ Unsintered PTFE, Buttrap	~ 6 mil
Champlain-20	Kapton / Extruded XL ETFE	5.7 mil

TEST FACILITY at UB

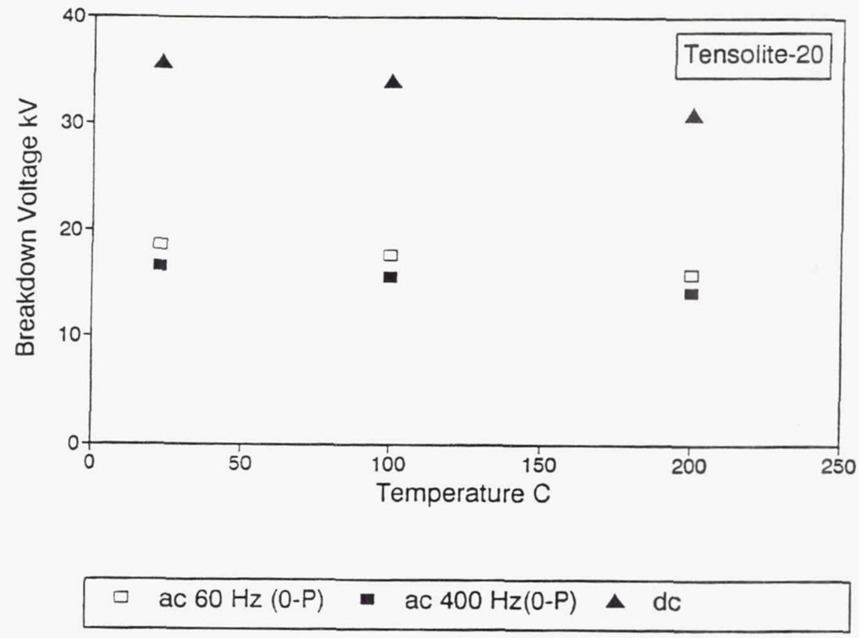



Gore-12
Breakdown Voltage kV
20
10
0
0
50
100
150
200
250
Temperature C
ac 60 Hz (0-P)
ac 400 Hz(0-P)
dc

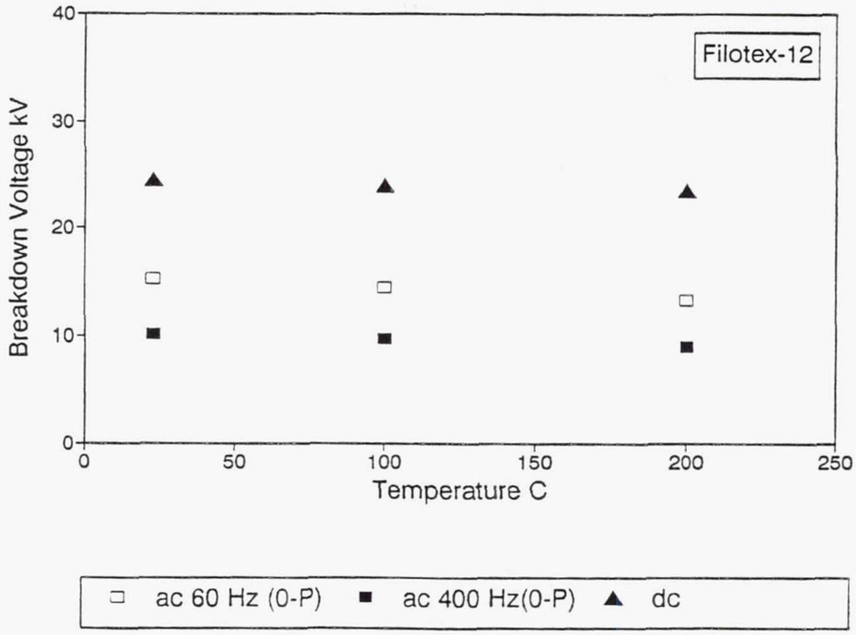

Gore-20
Breakdown Voltage kV
20
10
0
0
50
100
150
200
250
Temperature C
ac 60 Hz (0-P)
ac 400 Hz(0-P)
dc

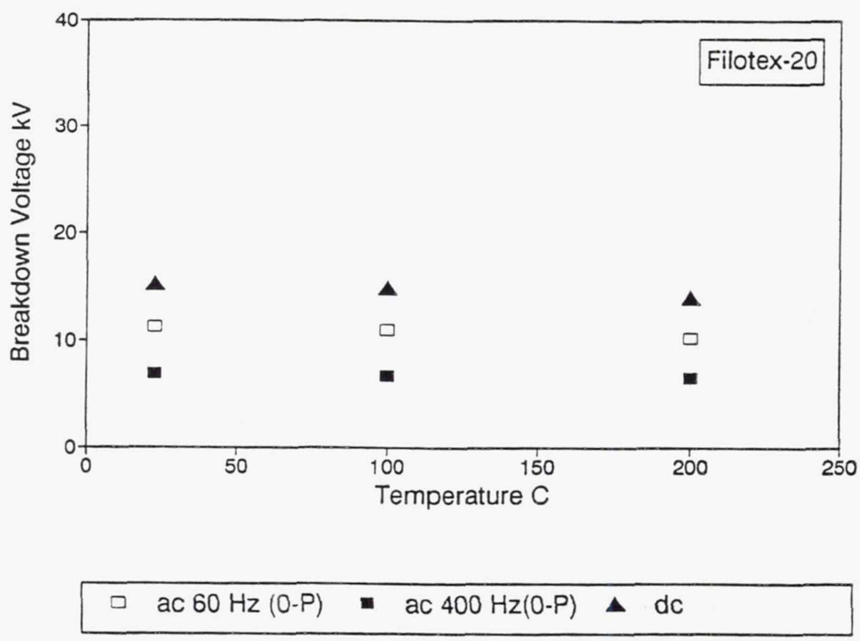


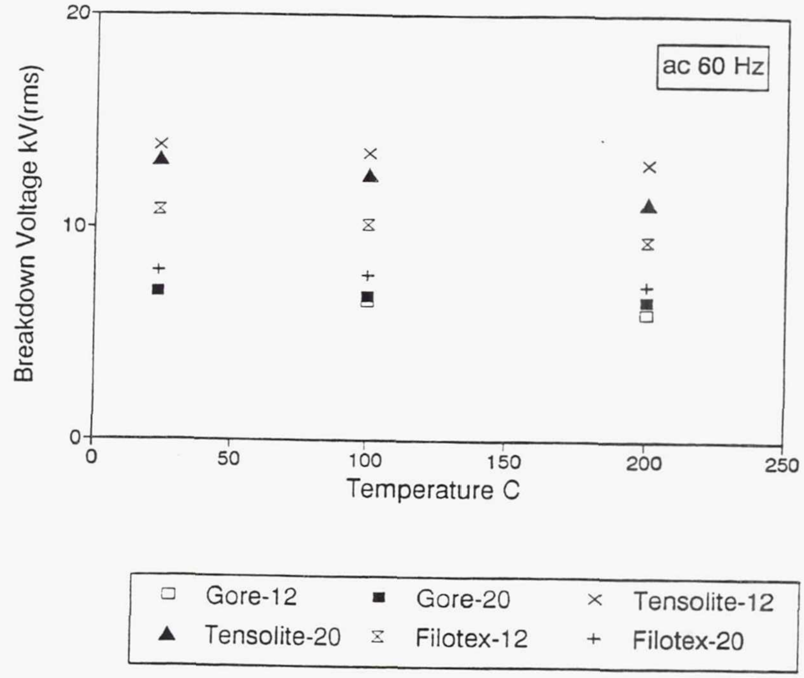
Tensolite-12
Breakdown Voltage kV
Temperature C
0
10
20
30
40
0
50
100
150
200
250
ac 60 Hz (0-P)
ac 400 Hz(0-P)
dc

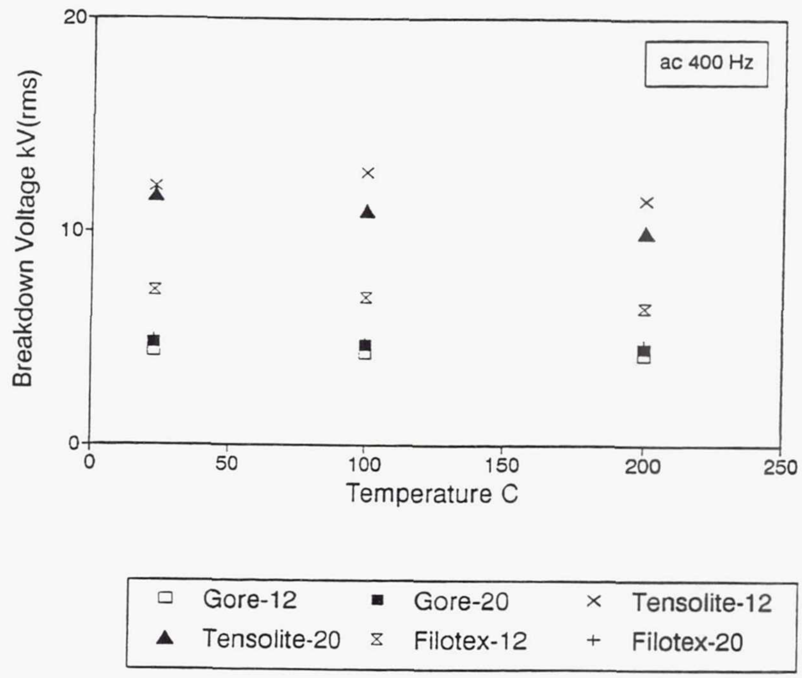


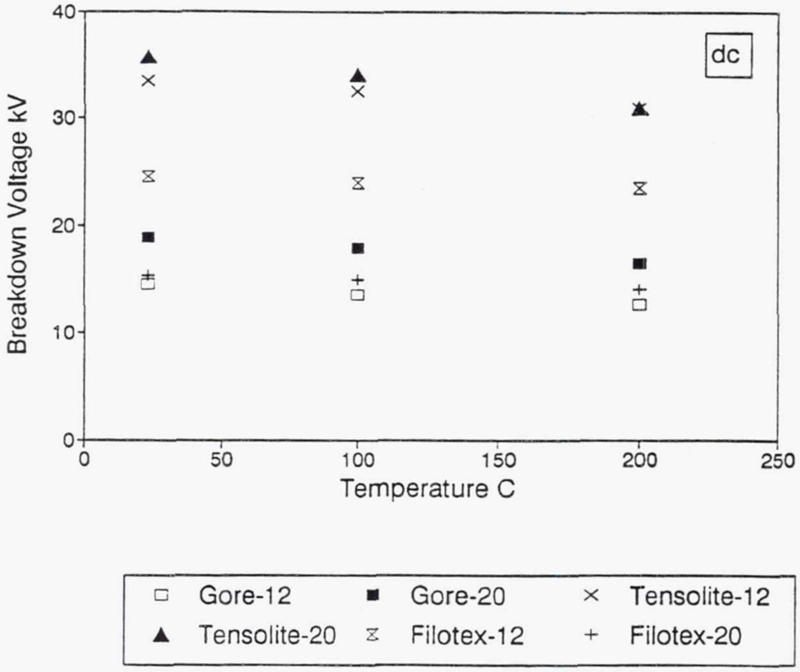
Tensolite-20
Breakdown Voltage kV
Temperature C
0
10
20
30
40
0
50
100
150
200
250
ac 60 Hz (0-P)
ac 400 Hz(0-P)
dc


Filotex-12
Breakdown Voltage kV
Temperature C
0
10
20
30
40
0
50
100
150
200
250
ac 60 Hz (0-P)
ac 400 Hz(0-P)
dc


Filotex-20
Breakdown Voltage kV
Temperature C
0
10
20
30
40
0
50
100
150
200
250
ac 60 Hz (0-P)
ac 400 Hz(0-P)
dc


ac 60 Hz
20
10
0
0
50
100
150
200
250
Breakdown Voltage kV(rms)
Temperature C
Gore-12
Gore-20
Tensolite-12
Tensolite-20
Filotex-12
Filotex-20


ac 400 Hz
20
10
0
0
50
100
150
200
250
Breakdown Voltage kV(rms)
Temperature C
Gore-12
Gore-20
Tensolite-12
Tensolite-20
Filotex-12
Filotex-20



FUTURE WORK

- Obtain breakdown strength of other constructions.
- Insulation resistance as a function of temperature.
- Multistress aging
  (Electrical, Thermal and Radiation

CONCLUSION

- No dependence of breakdown strength on temperature for constructions tested.
- Little effect of frequency on the breakdown characteristics.

A NEW TEST METHOD FOR THE ASSESSMENT OF THE ARC TRACKING PROPERTIES OF WIRE INSULATION IN AIR, OXYGEN ENRICHED ATMOSPHERES AND VACUUM

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Published Information on the Activities of the Cooperating Group THD / ERNO / ESA-ESTEC

[1]	F. Dricot, H.J. Reher	Survey of Arc Tracking on Aerospace Cables and Wires. Post–Deadline Proceedings of the XVth Intern. Symp. on Discharges and Electrical Insulation in Vacuum, September 6 – 10, 1992, Darmstadt, Germany, pp. 24 – 30, to be published in IEEE Trans. on Electrical Insulation
[2]	D. König, F.R.Frontzek F. Dricot, H.J. Reher M.D. Judd	Principle of a New Arc Tracking Test of Cables and Wires for Spacecraft. Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), October 18 – 21, 1992, Victoria, BC, Canada, pp. 363 – 369
[3]	ESA/ESTEC	Survey of Arc–Tracking. Final report, October 1991, submitted by MBB/ERNO. Internal paper. Authors: F. Dricot, H.J. Reher
[4]	M.D. Judd	Presentation of Activities in the Field of Arc Tracking of Wire Insulations (ESA/ERNO) Materials And Processes Technical Interchange Meeting, Reston, VA, September 1 – 3, 1992
[5]	ESA/ESTEC	Arc Tracking Test of Wires. Report of Phase 1. January 1993, submitted by ERNO. Internal paper. Authors: F. Dricot, H.J. Reher
[6]	D. König, F.R.Frontzek H.J. Reher, M.D Judd	A New Test Method for the Assessment of the Arc Tracking Properties of Wire Insulation in Air, Oxygen Enriched Atmospheres and Vacuum. 6th Int. Symp. on the Flammability and Sensitivity of Materials in Oxygen Enriched Atmospheres, Noordwijk, May 11 – 13, 1993 (oral presentation)

Contents

Tracking

A Phenomenon on the surface of the insulation materials
(Def. of G.A. Day)

ARC

A kind of electr. discharge mainly between two or more conductors
(Def. of Compton)

Arc Tracking

Interaction of different phenomena causing arcing and fault propagation in wire bundles

A. G. DAY

Tracking

TRACKING is an untidy process; its incidence depends upon the insulation but its inception depends upon several other factors. By definition, tracking is the formation of a permanent conducting path across a surface of the insulation, and in most cases the conduction results from degradation of the insulation itself. It is therefore necessary for organic insulation to be present if tracking is to occur.

The three essentials of the tracking phenomenon are:

(1) the presence of a conducting film across the surface of the insulation,
(2) a mechanism whereby the leakage current through the conducting film is interrupted with the production of sparks,
(3) degradation of the insulation must be caused by the sparks.

Definition of an Arc

Probably the best definition of an arc is that due to Compton; namely,

the arc is a discharge in a gas or vapor with a voltage drop in the cathode region that is *of the order of* the lowest ionization potential of the gas or vapor in which it burns.

The voltage of short arcs is usually in the range 10 - 50 V. This arc drop is divided between *anode* and *cathode* drops (usually of the order of 10 V; often the anode drop is considerably higher than the cathode drop) and the balance in the column that depends on its length. Arc currents are usually from the order of one to many thousands amperes.

ARC TRACKING TESTS

Development of wet arc tracking test methods

Initiated by incidents of arcing recorded under wet conditions: e.g. a failure of a cable bundle on a Monarch Airlines aircraft caused by a leaking toilet.

Development of dry arc tracking test methods

Other incidents of arc ignitions recorded in dry conditions (mechanical damage of insulation, electrical sparks etc.)

Comparison of existing test methods

Conclusion: No appropriate arc tracking test for space application available

Aim:

Development of a new test method suitable for the assessment of the resistance of areospace cables to arc tracking for different specific environmental and network conditions of spacecrafts

Table 1. Comparison of Test Methods (published at CEIDP, 1992)

Test method comparison	Test methods:							
	[8]	[9]	[6]	[7]	[12]	[13]	[10]	[11]
1. Electric circuit 1.1. Power source								
a) AC,200/115V,400Hz	+	+	+	var	–	+	–	–
b) DC	–	–	–	var	var	–	–	–
c) others	–	–	1)	2)	–	–	3)	4)
1.2. Current								
a) same value for all cable sizes and types	+	+	–	–	–	+	1A	5)
b) dependent from the nominal current of the tested cable	–	–	+	+	+	–	–	–
c) dependent from the protective device of the tested cable	–	–	+	+	–	–	–	–
1.3. Relation to recovery voltage	–	–	–	–	–	–	–	–
2. Arc ignition process								
a) wet ignition method	+	–	+	–	–	–	+	–
b) dry ignition method	–	+	+	+	+	+	–	+
3. Arc burning time limited by								
a) protective circuit breaker	+	+	+	+	+	+	+	–
b) self-extinction of the arc	+	+	+	+	+	+	+	+

1) DC, 28 V, 2) DC+AC
3) AC, 100V...600V
4) DC, 220V
5) limited by R = 20 Ω
6) ∠ 10°
7) wet = L, dry = S

(+) = yes; (–) = no
L – large (≤ 8h), S – short
? = no statement
var = variable

[6] Aerospatiale Test 480.202/87A: Electrical Cables. Aerospatiale Test Methods for Investigations of the Arc Tracking Design.

[7] ASTM D 09.16 (October 89): Dry Arc Resistance and Fault Propagation.

[8] BSG 230 Test 42: Resistance to Wet Arc—Tracking.

[9] BSG 230 Test 43(Draft): Dry Arc Test.

[10] IEC 112/VDE 0303, Teil 1: Method for Determining the Comparative and the Proof Tracking Indices of Solid Insulating Materials under Moist Conditions (VDE Specification).

[11] DIN VDE 0303, Teil 5: Testing of Electrical Insulating Materials — Low—Voltage High—Current Arc Resisting Test (in German).

[12] NASA TP WSTF—655: Arc Resistance in Space Grade Wires.

[13] NHB 8060.1C Test 18: Arc—Tracking.

Table 1. Comparison of Test Methods (continued)

Test method comparison	Test methods: [8]	[9]	[6]	[7]	[12]	[13]	[10]	[11]
4. Influence from environment *conditions*								
a) Air under atmospheric pressure	+	+	+	+	+	+	+	+
b) Air with enriched O_2	–	–	–	–	–	+	–	–
c) Vacuum	–	–	–	–	–	?	–	–
d) Mechanical vibration	–	+	–	–	–	–	–	–
5. Preparation and position of the sample								
a) only insulation material used for the cable construction	–	–	–	–	–	–	+	+
b) a part of wire or cable bundle	+	+	+	+	+	+	–	–
c) insulation artificially damaged	+	+	+	+	+	+	–	–
d) position								
– vertical	–	–	–	+	+	?	–	–
– horizontal	–	+	–	–	–	?	+	+
– other	6)	–	6)	–	–	?	–	–
6. Test duration	L	S	7)	S	S	S	S	S
7. Evaluation criteria								
a) Burning time of the arc	–	–	–	+	+	–	–	+
b) Length of the arc path	+	+	–	–	+	+	–	+
c) Insulation resistance measurement	+	+	–	–	–	–	–	+
d) Electric strength test	–	+	–	–	+	–	–	–
e) Continuity test of conductors	+	+	–	–	–	–	–	–
f) Visual evaluation	+	+	+	+	+	+	–	–

[6] Aerospatiale Test 480.202/87A: Electrical Cables. Aerospatiale Test Methods for Investigations of the Arc Tracking Design.

[7] ASTM D 09.16 (October 89): Dry Arc Resistance and Fault Propagation.

[8] BSG 230 Test 42: Resistance to Wet Arc–Tracking.

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[12] NASA TP WSTF–655: Arc Resistance in Space Grade Wires.

[13] NHB 8060.1C Test 18: Arc–Tracking.

PRINCIPLES OF A NEW ARC–TRACKING TEST

The following principles have been incorporated into the new test method.

a. Test equipment enables wires to be tested in vacuum, normal air (atmospheric pressure) and in an enriched oxygen atmosphere (at atmospheric and reduced pressure).

b. The supply voltage is adjustable. During test the current is initially set on the nominal current rating (including derating if applied) of the cable. Subsequent tests should be performed at different current values to assess the capability of the wire to withstand stress.

c. The arc is ignited by melting of an ignition wire (filament) ensuring that the influence of the ignition on the arc behaviour is minimised.

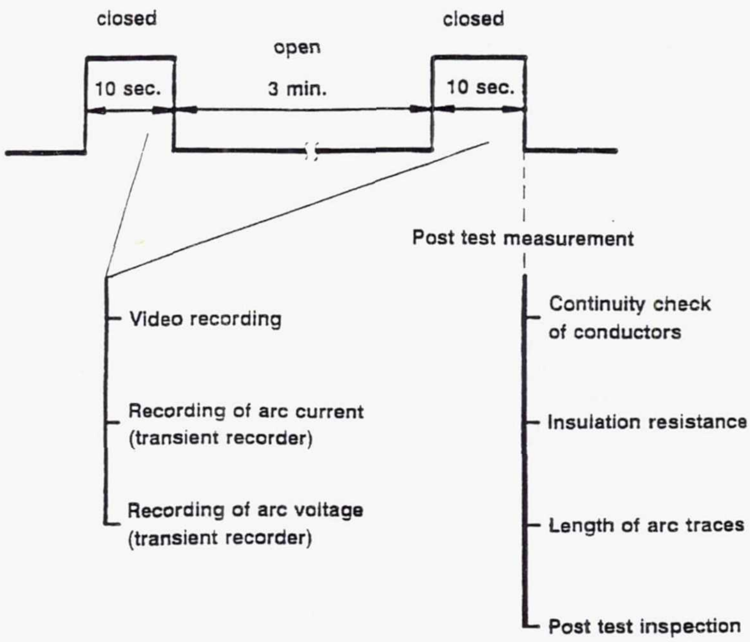
d. Switching cycles are applied to the test voltage (presently 10 sec. on, 3 min. off and a further 10 sec. on).

e. Damage is induced in the cable in a clearly defined location.

f. Evaluation criteria should be based on the test results and on any post test measurements such as:

Remaining "conduction function" of the conductors
Post test insulation state of damaged and/or undamaged cable bundles
Arc duration and path length
Measurement of electrical characteristics during test
Visual records and post test inspection

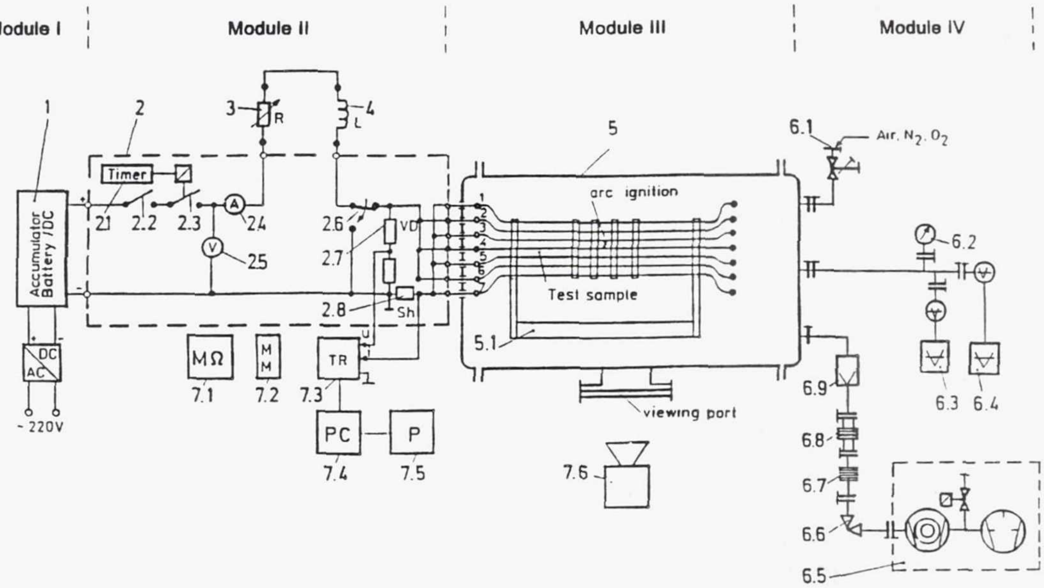
Switching Cycle, Measurements and Evaluation Criteria



Accept/Reject Criteria: still under consideration

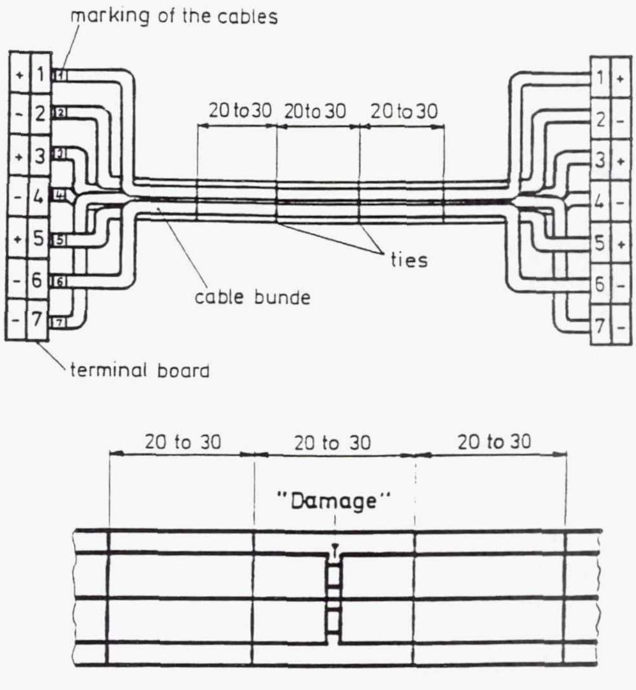
Basic ideas: Simple criteria based on selected post test measurements; support by electrical and optical records taken during test.

Scheme of the Arc Tracking Test Arrangement

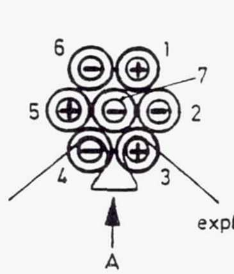


Explanation of Symbols: see [5]

Test sample configuration



View on arrow A



Cables Nr. 3 and 4: damaged
Cables Nr. 1, 2, 5, 6 and 7: undamaged

Test Procedure (Draft)

a. Prepare test samples as described earlier and install in chamber.

b. Establish test atmosphere.

c. Adjust current to nominal rating for wire under test.

d. Activate test recording devices (video, transient recorder etc.)

e. Power to the test sample should be activated for 10 seconds to initiate the arc and then deactivated. After a period of 3 minutes power to the sample initiated for a further 10 seconds to test for arc tracking potential and damage.

f. During test the sample shall be observed and video recorded. Arc current and arc voltage are recorded by the transient recorder.

g. After test the following measurements are made:
- Electrical resistance of the conductors of the sample,
- Insulation resistance between damaged and / or undamaged wires. A value of at least 0,5 MΩ at 500 V DC is required.

h. If the test sample fails the test should be repeated on a new sample at a lower test current.

Typical Test Results:
4 different arc extinction patterns

The following four typical arc extinction patterns have been observed:

1. Self–extinguishing arc without reignitions (SE)

2. Arc extinction caused by metallic short circuiting of the conductors (M)

3. Arc extinction caused by low resistance short circuiting of the conductors (R) (conductive material generated from molten insulating material and conductors bridging the conductors)

4. Arc extinction caused by clearing of the control circuit breaker (CI) (Under practical conditions a stable arc with a duration exceeding the test duration time of 10 sec. has to be expected)

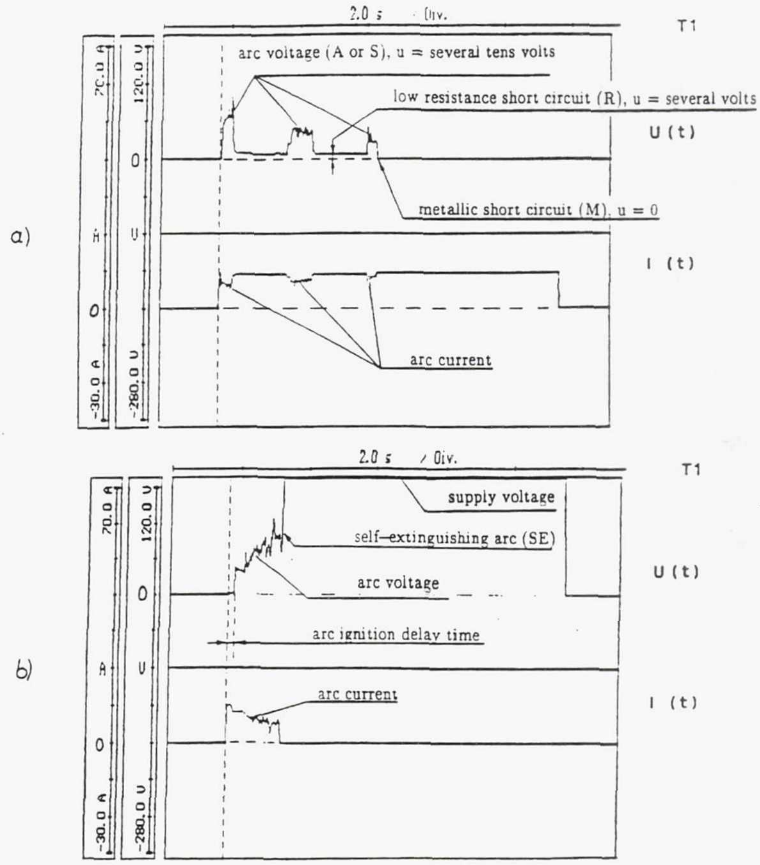


Fig. 4 a/b. Typical records of test current I (t) and voltage U(t) between the conductors during the time T1 of the switching cycle.

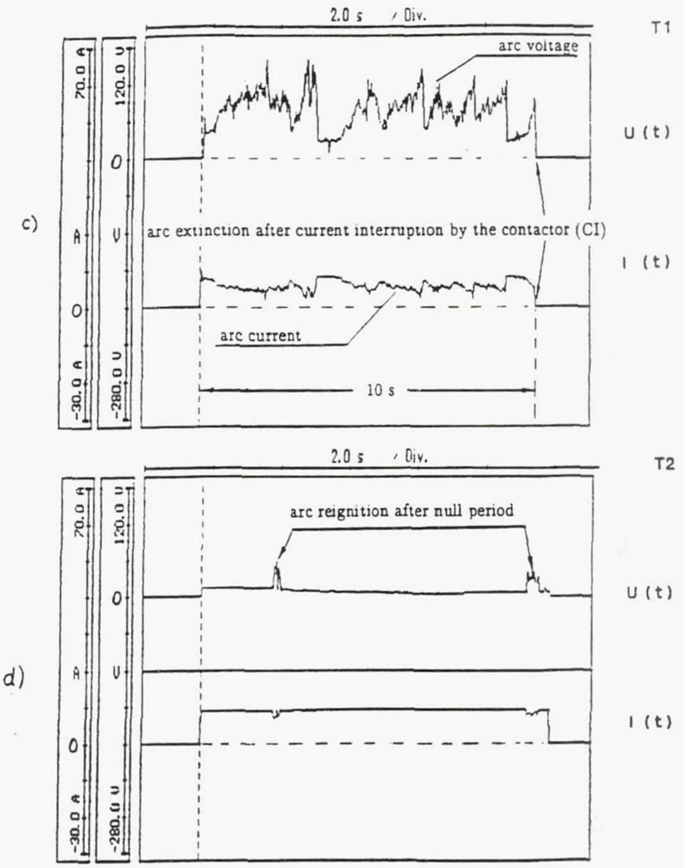


Fig. 4 c/d. Typical records of test current I(t) and voltage U(t) between the conductors during the time T1 (c) and the time T2 (d) of the switching cycle.

Arc Tracking Test of Wires
Experimental Results

Abbreviations

Abbreviation	Meaning	Source
M -	Metallic short circuit	Information from recording of current and voltage with a transient recorder
R -	Low resistance short circuit	
SE -	Self-extinguishing arc	
CI -	Arc extin-ction after the current interruption by the contactor	
NR -	No arc reignition	
A -	Massive arcing	Information from video recording
S -	Short arcing	
CF -	Consuming fire	
SF -	Short duration fire	
G -	Glow if current flows	
SS -	Short spit	
NA -	No action	
Y -	Yes	After test electrical measurements
N -	No	

Table A. 8

Sample No.: 7/20 — Wire size: AWG 20

Test voltage: 125 V — Test current: 10 A

Time 1: 10 s — Switching cycle: Null period (Power off): 3 min. — Time 2: 10 s

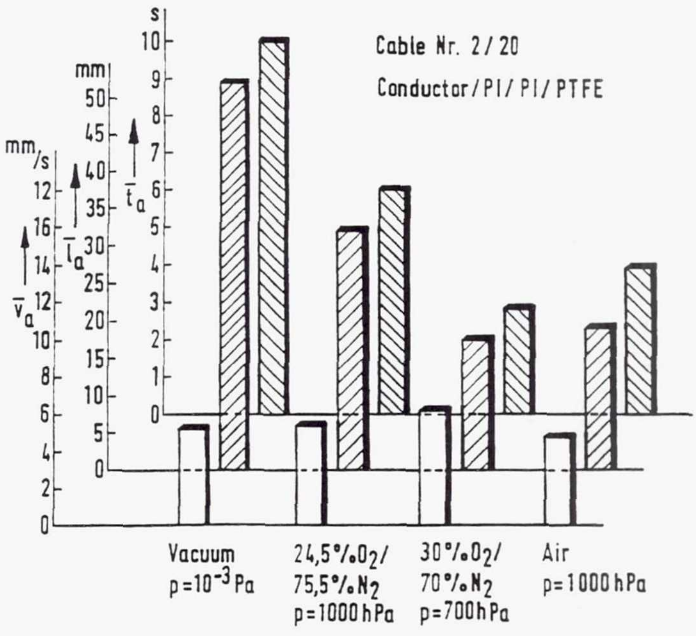
		Environmental Conditions					
		Normal atmosphere		Atmosphere with enriched oxygen		Vacuum	
Post test measurements	Test No.	1	2	3	4	5	6
1. Arc duration in s	T_1	0.55	0.43	1.4	0.85	1.1	1.6
	T_2	0	0	0	0	0	0
2. Total burn length in mm		13	10	15	11	16	18
3. End to end wire continuity check. Wire No.:	1	Y	Y	Y	Y	Y	Y
	2	Y	Y	Y	Y	Y	Y
	3	N	N	Y	N	N	N
	4	Y	N	N	N	Y	Y
	5	Y	Y	Y	Y	Y	Y
	6	Y	Y	Y	Y	Y	Y
	7	Y	Y	Y	Y	Y	Y
4. Insulation resistance lower than 0.5 MΩ measured for the following wires:			3 4			3 4	3 4
						1 2 5 6 7	1 2 5 6 7
5. Observations							
A) Transient recorder: Time 1		SE	M	SE	SE	SE	SE
Time 2		NR	M	NR	NR	NR	NR
B) Video recorder: Time 1		S	S	A,SF	S,SF	S	S
Time 2		NA	NA	NA	NA	NA	NA

Table A. 9

Sample No.: 1/12			Wire size: AWG 12
Test voltage: 125 V			Test current: 30 A
Time 1: 10 s	Switching cycle Null period (Power off): 3 min.		Time 2: 10 s

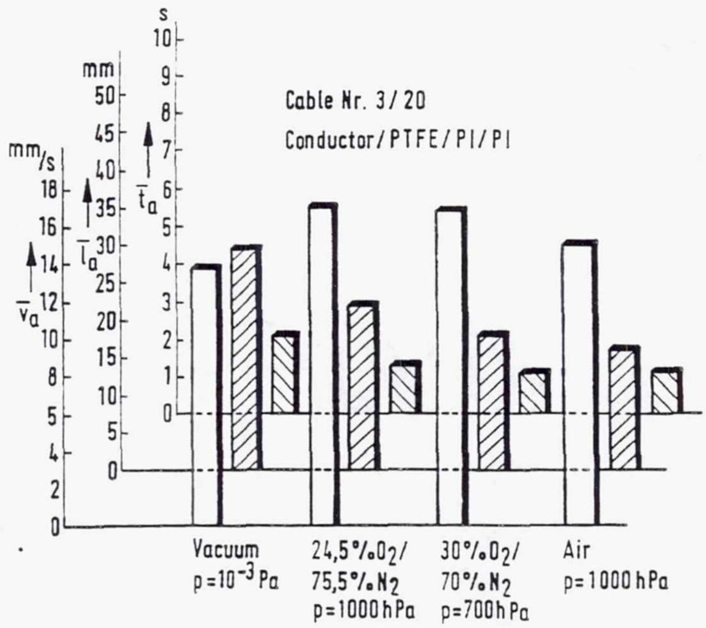
		Environmental Conditions					
		Normal atmosphere		Atmosphere with enriched oxygen		Vacuum	
Post test measurements	Test No.	1	2	3	4*	5	6
1. Arc duration in s	T_1	1.2	1.4	2.9	1.6	0.72	1.4
	T_2	0	0	0	0	0	0
2. Total burn length in mm		12	24	40	9	21	13
3. End to end wire continuity check. Wire No.:	1	Y	Y	Y	Y	Y	Y
	2	Y	Y	Y	Y	Y	Y
	3	Y	Y	N	Y	Y	Y
	4	N	Y	Y	Y	Y	Y
	5	Y	Y	Y	Y	Y	Y
	6	Y	Y	Y	Y	Y	Y
	7	Y	Y	Y	Y	Y	Y
4. Insulation resistance lower than 0.5 MΩ measured for the following wires:		3 4	3 4	3 4	3 4	3 4	3 4
		2 7	7	7	2 7	1 2 5 6 7	1 2 5 ~~7~~6 7
5. Observations							
A) Transient recorder: Time 1		R	R	R	R	R	R
Time 2		R	R	R	R	R	R
B) Video recorder: Time 1		A,CF	A,CF	A,CF,G	A,SF,G	A,G	A,G
Time 2		SF,G	CF,G	G	NA	G	G

* – test current 10 A



Average values of arc duration $\bar{t}_a$, length of arc traces $\bar{l}_a$ and arc propagation velocity $\bar{v}_a$ for cable Nr. 2/20 tested under different environmental conditions.

Number of tests for each environmental condition N=5.



Average values of arc duration $\bar{t}_a$, length of arc traces $\bar{l}_a$ and arc propagation velocity $\bar{v}_a$ for cable Nr. 3/20 tested under different environmental conditions.
Number of tests for each environmental condition N=5.

PRELIMINARY TEST RESULTS
ARC TRACKING TEST OF WIRES

TABLE 1. TEST SAMPLE 1/12 (Cable size AWG 12)

Test–Nr.	Path length of damaged cable insulation in mm	Number of cables with insulation resistance < 0.5 MΩ
1 N	12	2
2 N	24	1
1 E	40	1
2 E	9	**2**
1 V	21	5
2 V	13	5

N – Normal atmosphere, E – Oxygen enriched atmosphere, V – Vacuum

<u>Conclusion</u>: The path length of damaged cable insulation seems to be not correlated with the results of post–test measurements of the cable insulation resistance

High number of tests

Sample No.	ESA SCC-SPEC	No. of Cores	Wire Size AWG	Material Plating	Insulation Layers
1/20	3901 001	1	20	Co/Silver	PI PI PI (protective coating)
1/12		1	12	.	. . .
1 A/20	3901 002	1	20	.	PI PI (protective coating)
2/20	3901 007	1	20	.	PI HR616 PI HR616 PTFE 50 % max. overl.
2/12		1	12	.	. . .
3/20	3901 009	1	20	.	PTFE expanded PI HR616 PI HR616
3/12		1	12	.	. . .
4/20	3901 012	1	20	.	ETFE extruded
6/20	-	1	20	.	PTFE tape PI 51 % overl. PTFE varnish
7/20	3901 013	1	20	.	PTFE expanded PI coating
5/20	-	1	20	.	

ETFE = Ethylene Tetrafluoro-Ethylene PI = Polymide PTFE = Polytetrafluorethylene

TEST ACCEPTANCE CRITERIA (Draft)

1. For a defined test voltage, test current and for a defined environment, all conductors of all five test specimens tested have to pass the continuity test and

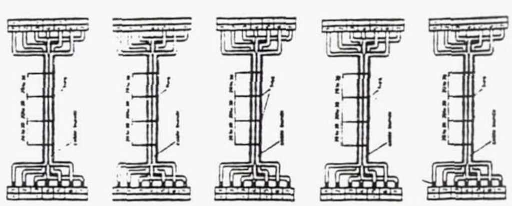
2. All cables/wires of all five test specimens tested without the predamaged cables/wires have to fulfil the requirements of insulation resistance test, i.e. the insulation resistance between the cable/wire under test and the other cables/wires of a test specimen short–circuited must be higher then 0.5 MΩ.

3. During the re–application of the power for 10 seconds following the three minutes pause no visible arc and/or glow activity is acceptable.

4. If only one cable/wire of all tested *specimens fails*, additional three specimens have to be tested. If during these additional test series the Accept criteria 1, 2 and 3 are fulfilled, the cable has passed the test successfully.

If these requirements have been met for the specified environmental conditions then the cable tested shall be classified as <u>resistant to arc tracking</u> for a given test voltage and currents below or equal to the test current with respect to this *environmental condition*.

5 TEST SPECIMENS OF 7 CABLES/WIRES EACH



IF ONLY ONE CABLE/WIRE FAILS → ADDITIONAL 3 TESTS

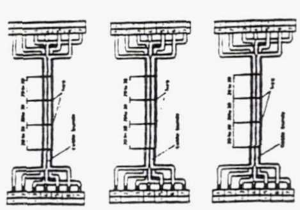


Table 2 Test Results and Acceptance Statement

Cable specification: ESA SCC-Spec. 3901/007
Cable size: AWG 20 (0,52 mm^2)
Rated current: 7,5A at max. ambient temperature of 85°C

Test voltage: 125 V

Environmental conditions (E.C.):
1. Normal atmosphere (N)
2. Vacuum (V)

Test-current	E.C.	Test - Nr.	Criterion 1 Number of cables that fail the continuity check of conductors (1...7)	Criterion 2 Number* of cables with an insulation resistance ≤ 0,5MΩ (1...5)	Criterion 3 Visible arc or glow activity during re-application of the power (Yes/No)	Accepted Yes/No
10A	V	1	1	2	N	N
	N	1	2	2	N	N
7,5A	V	1	1	1	N	N
		2	1	1	N	N
	N	1	0	0	N	Y
		2	0	0	N	Y
		3	0	0	N	Y
		4	0	0	N	Y
		5	0	0	N	Y

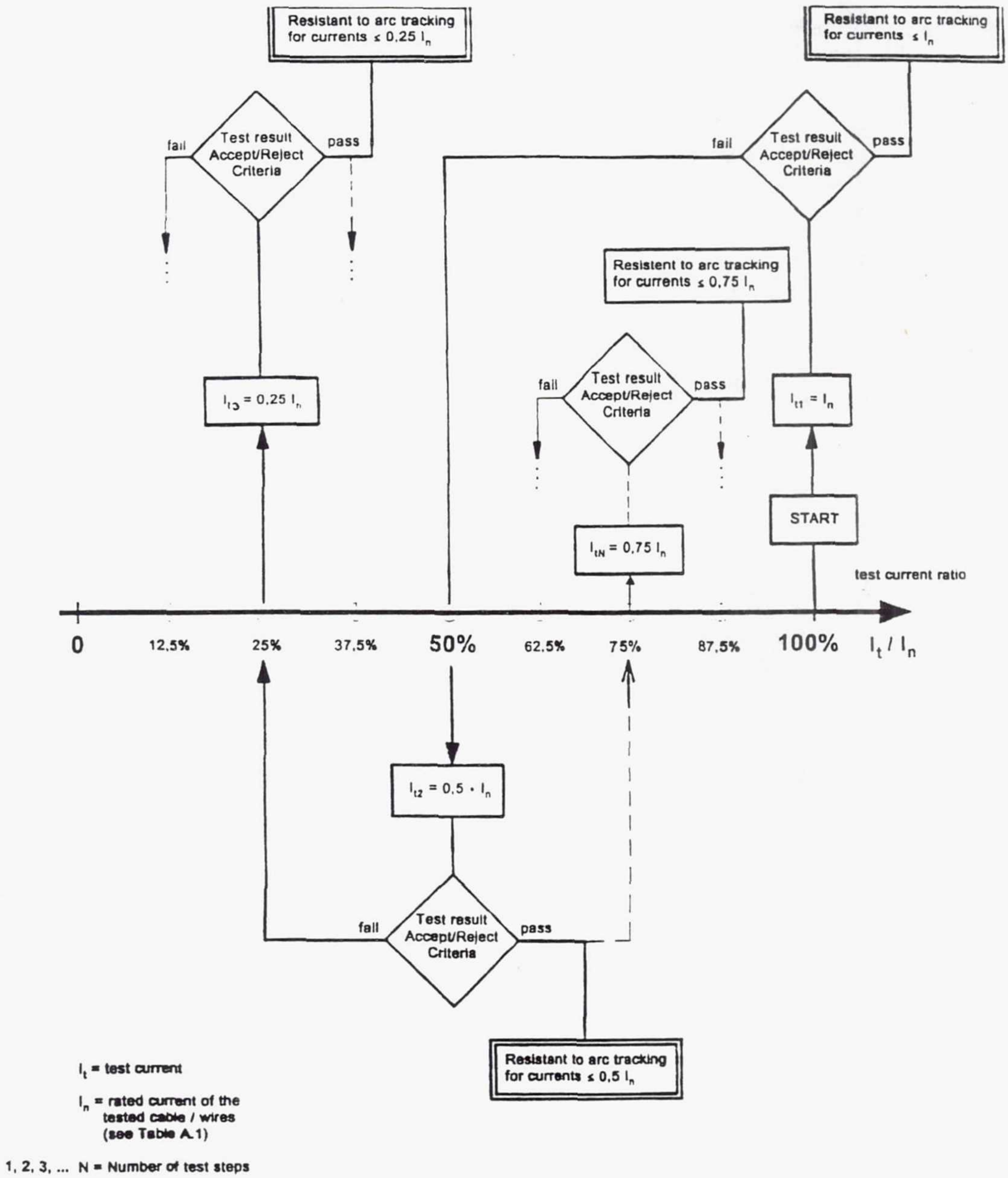
Test Result:
The above specified cable is resistent to arc tracking for current values ≤ 7,5 A at the rated voltage of 125 V and for the environmental conditions defined as:
Normal atmosphere, p = 0,1 MPa

■ Yes

□ No

* without the pre-damaged cables Nr. 3 and Nr.4

Procedure for an estimation of the arc tracking current limit



Conclusion

A brief summary of the results obtained is given below. However, it should be remembered that the conclusions drawn are based on limited series of tests and further work needs to be done to investigate the effects of different parameters. In addition, presently accept/reject criteria can be given only as a draft. Modifications may become necessary, if required by findings from a more extensive data base.

The results can therefore be summarised as follows:

a. The proposed test method appears to be a useful tool for the assessment of wire insulation systems under arc tracking stress.

b. The equipment can be easily adapted for tests at different realistic electrical network conditions incorporating circuit protection.

c. The test system works equally well whatever the test atmosphere.

d. Initial test results confirm published results of the available literature in that pure Kapton insulated wire has bad arcing characteristics and ETFE insulated wire is considerably better (in air).

e. Initial test results indicated that for certain wires arc tracking effects are increased at higher oxygen concentrations and significantly increased under vacuum. Although this letter point had been suggested from theoretical considerations it is believed that this is the first time this has been demonstrated in practice.

f. All tests on different cable insulation materials and performed in different environment including enriched oxygen atmospheres resulted in a more or less rapid extinguishing of all high temperature effects at the beginning of the post-test phase. In no case a self-maintained fire was initiated by the arc.

HIGH TEMPERATURE POLYMER DIELECTRIC FILM INSULATION

Robert J. Jones
TRW
Redondo Beach, California

HIGH TEMPERATURE POLYMER DIELECTRIC FILM INSULATION

BACKGROUND

- DUAL USE SYSTEM DRIVERS FOR DEVELOPMENT, QUALIFICATION AND PRODUCTION OF NEXT GENERATION, VERY HIGH TEMPERATURE WIRE INSULATION
  - ENERGY RECOVERY/GENERATION/DISTRIBUTION AND TRANSPORTATION MARKETS (1990's)
  - SUPER CAPACITY/RESPONSE ELECTRONIC COMPUTATION AND TELECOMMUNICATION EQUIPMENT (1990's)
  - HIGH SPEED CIVIL TRANSPORT (NEXT CENTURY)
  - ALL ELECTRIC AIRPLANE (NEXT CENTURY)

- EXAMPLES OF SYSTEM RATIONALE FOR VERY HIGH TEMPERATURE WIRE INSULATION
  - SMALLER, MORE EFFICIENT ELECTRONIC SYSTEMS RUN HOTTER
  - OPERATING ENVIRONMENTS SUCH AS DOWNWELL ARE GETTING MORE THERMALLY SEVERE
  - ACTIVE COOLING SYSTEMS FOR GENERATORS/ALTERNATORS, STORAGE/TRANSMISSION/ DISTRIBUTION SYSTEMS AND BLACK BOXES ARE COSTLY AND EQUATE TO SEVERE WEIGHT PENALTIES
  - SMALLER DIAMETER WIRES MAY BE SUFFICIENT TO CARRY EQUIVALENT POWER

HIGH TEMPERATURE POLYMER DIELECTRIC FILM INSULATION

BACKGROUND (CONTINUED)

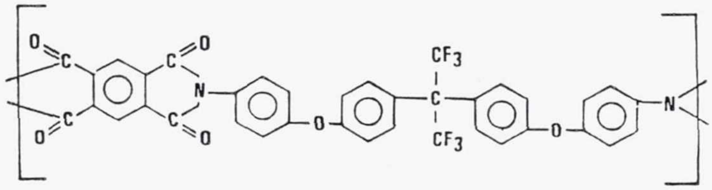
- ASSESSMENT OF EMERGING REQUIREMENTS HAS DICTATED THAT 300°C PERFORMANCE IS THE GOAL FOR NEXT GENERATION WIRE INSULATION
  - VERY SIGNIFICANT INCREASE OVER CURRENTLY QUALIFIED POLYIMIDE AND FLUOROPOLYMERS RATED AT 200°C (OR SLIGHTLY ABOVE)
  - EMERGING HIGH TEMPERATURE POLYMER MATERIALS HAVE BEEN SHOWN TO HAVE POTENTIAL FOR PERFORMANCE AT ≥300°C
  - ≥300°C INSULATIONS SHOULD MEET NEW DUAL USE PERFORMANCE REQUIREMENTS WELL INTO NEXT CENTURY

- STATUS OF RECENT OR CURRENT 300°C POLYMERIC WIRE INSULATION ACTIVITY
  - UBE INDUSTRIES OFFERED UPILEX® S FILM, BUT WITHDREW IT FROM THE MARKET IN 1992
  - FOSTER MILLER IS STUDYING LIQUID CRYSTAL POLYMERS
  - 3M IS DEVELOPING FPE POLYMER MATERIAL
  - TRW HAS SHOWN HIGH PROMISE FOR ITS PFPI POLYMERS UNDER USAF SPONSORSHIP (FINAL REPORT WL-TR-91-2105); FURTHER WORK WILL BE CONDUCTED IN RECENTLY AWARDED USAF CONTRACT F33615-93-C-2367

HIGH TEMPERATURE POLYMER DIELECTRIC FILM INSULATION

TRW PFPI AS SUPERIOR 300°C POLYMER CANDIDATES

- REPRESENTATIVE CHEMISTRY



US PATENT NUMBERS 4,111,906; 4,196,277; 4,203,922; 4,880,584

(PFPI POLYMERS WERE INVENTED UNDER NASA LEWIS RESEARCH CENTER SPONSORSHIP IN THE LATE 1970's)

- VERSATILITY
  - FORMULATIONS CAN BE TAILORED TO MEET PRODUCT USE REQUIREMENTS
  - COATING VARNISH, FILM AND POWDER PRODUCT FORMS CAN BE EMPLOYED TO ADAPT FORMULATIONS TO EXISTING PROCESSING EQUIPMENT FOR CONVERSION TO WIRE INSULATION
  - POLYMERS POSSESS SUPERIOR COMBINATION OF THERMAL/ELECTRICAL/UV, MOISTURE & FLUID RESISTANCE/TRIBOLOGICAL PROPERTIES
  - FILMS ARE AMENABLE TO CERAMIC COATING FOR LEO ATOMIC OXYGEN PROTECTION

HIGH TEMPERATURE POLYMER DIELECTRIC FILM INSULATION

TRW PFPI AS SUPERIOR 300°C POLYMER CANDIDATES (CONTINUED)

- COMPARISON OF PROMISING PFPI FILM PROPERTIES WITH KAPTON® (FROM REPORT WL-TR-91-2105)

PROPERTY MEASURED	PROPERTY RESULT[A)]	
	KAPTON FILM	TRW PFPI FILM
ELECTRICAL		
• DIELECTRIC CONSTANT		
- AT 25°C	3.1	3.1
- AT 300°C	2.8	2.9
• DISSIPATION FACTOR		
- AT 25°C	0.001	0.001
- AT 300°C	0.063	0.004
• BREAKDOWN VOLTAGE AT 25°C (V/MIL)		
- AC	7000	6000
- DC	11000	12000
LOW TEMPERATURE STABILITY (CRYOGENIC)		
• EXPOSURE IN LIQUID NITROGEN AND HELIUM	NO EFFECT	NO EFFECT
AIR AGING AT 300°C		
• WEIGHT LOSS AFTER 1000 HRS (%)	13.0	4.1
HUMIDITY AGING AT 90°C/100% RH		
• WEIGHT LOSS AFTER 1200 HRS (%)	FAILED AFTER 500 HRS	0.4
BASIC SOLUTION (PH, 10) AGING AT 93°C		
• WEIGHT LOSS AFTER 96 HRS (%)	2.6	1.3
ULTRAVIOLET LIGHT AGING AT 25°C		
• WEIGHT LOSS AFTER 1000 HRS (%)	6.7	1.4

A) ALL PROPERTIES DETERMINED ON 0.001-INCH THICK FILMS

HIGH TEMPERATURE POLYMER DIELECTRIC FILM INSULATION

TRW'S PFPI AS SUPERIOR 300°C POLYMER CANDIDATES (CONTINUED)

- PROMISING BULK POLYMER OR COATING PROPERTIES

PROPERTY TYPE	PROPERTY MEASURED	TEST RESULT
THERMAL	• MELTING POINT • GLASS TRANSITION TEMPERATURE	≥400°C >300°C
TRIBOLOGICAL	• FRICTION COEFFICIENT	0.3-0.6(RT); 0.1-0.2 (300°C)
	• WEAR RATE	MUCH LOWER THAN TEFLON
COATING ENVIRONMENTAL RESISTANCE	• COATING INTEGRITY AFTER EXPOSURE TO: - 500 HRS, 343°C - 21 DAYS, 71°C IN MIL-H-5606 HYDRAULIC FLUID - 21 DAYS, 71°C IN MIL-L-7808 JET ENGINE OIL - 2000 HRS, 25°C IN 5% SALT SPRAY	NO BLISTERING OR LOSS OF ADHESION

HIGH TEMPERATURE POLYMER DIELECTRIC FILM INSULATION

TRW'S PFPI AS SUPERIOR 300°C POLYMER CANDIDATES (CONTINUED)

- DUAL USE CHALLENGES FOR 1994-1996 TIME FRAME
  - CONTINUING USAF WORK
    - •• VERIFY PROMISING INITIAL FILM AND COATING PROPERTIES AS A WIRE INSULATION
    - •• DEMONSTRATE A SUPERIOR 300°C ADHESIVE FOR WRAPPED FILM
    - •• ACHIEVE HIGH INSULATION RESISTANCE TO ARCING & TRACKING
    - •• ACHIEVE FACILE FILM WRAP PROCESSABILITY ON EXISTING PLANT EQUIPMENT AND PRODUCE HIGH QUALITY INSULATED WIRE
  - COMMERCIAL PRODUCT DEVELOPMENT
    - •• QUALIFY AND INTRODUCE PFPI INTO MAGNET WIRE INSULATION, AUTOMOTIVE COMPONENT COATING AND MEDICAL DIAGNOSTIC PRODUCT APPLICATIONS
    - •• MAXIMIZE HIGH VOLUME USE APPLICATIONS TO MINIMIZE FUTURE POLYMER COSTS
- PROPOSED ADAPTATION OF PFPI TO MEET FUTURE NASA 200°C SPACE SYSTEM WIRE INSULATION REQUIREMENTS
  - DETERMINE INITIAL BASELINE WIRE PROPERTIES SPECIFIC TO SPACE APPLICATION ON COATED OR WRAPPED WIRE
  - TAILOR EXISTING 300°C POLYMER CANDIDATE TECHNOLOGY, AS REQUIRED, TO OFFER OPTIMUM 200°C PERFORMANCE; BUILD UPON EURECA SAMPLE TEST RESULTS
  - PRODUCE OPTIMIZED INSULATED WIRE AND PERFORM QUALIFICATION TESTS FOR GENERAL AND MISSION SPECIFIC SPACE APPLICATIONS

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HIGH TEMPERATURE ARC-TRACK RESISTANT AEROSPACE INSULATION

William Dorogy
Foster-Miller, Inc.
Waltham, Massachusetts

FOSTER-MILLER, INC.

- 37 year old independent technology development company
- Located in the Boston area
- About 270 employees
- Primary areas of business
  - Advanced polymers
  - Composites
  - Robotics
  - Special machinery

MATERIALS TECHNOLOGY GROUP

- Mission
  - Develop materials and processing technology to meet DoD and commercial needs
- Specific Areas of Research
  - High temperature dielectric materials
  - High performance dielectrics for capacitors
  - Electronics packaging
  - High performance structural materials
  - Microcomposite blends
  - NLO materials, devices
  - Smart processing

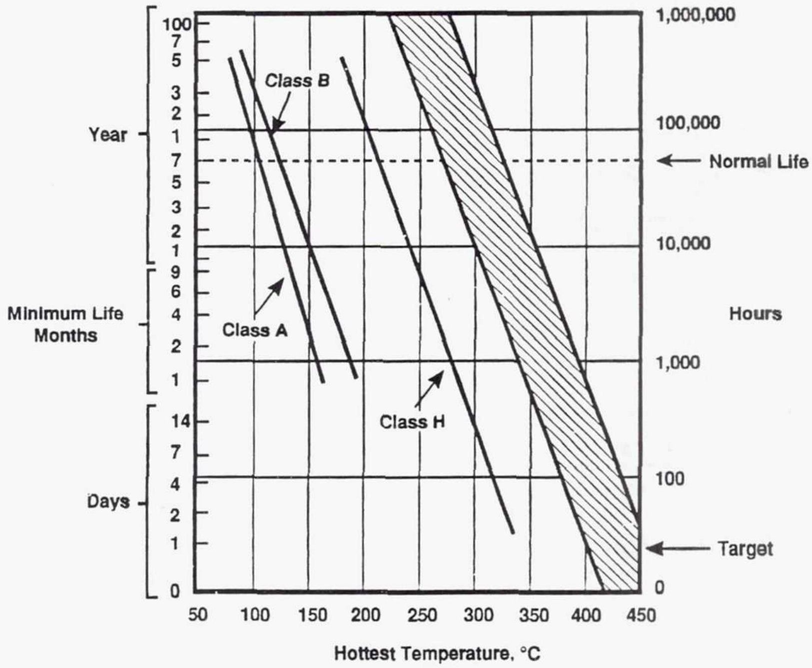
HIGH TEMPERATURE AEROSPACE INSULATION

- Goal
  - Identify and develop arc-track resistant insulation materials that can operate reliably at 300°C
- Phase I SBIR program, July 1991 to January 1992
- Monitored by Mr. George Slenski, and Mr. Eddie White of USAF Wright Laboratory/Materials Directorate
- Phase II program: October 1992 to September 1994
- Contract monitors: Lt. Tim Townsend and Mr. Robert Andes

COMPARISON OF CURRENT MATERIALS AND MATERIALS UNDER DEVELOPMENT FOR AEROSPACE INSULATION

Insulation Material	Max Use Temp. °C	Arc-Tracking	Advantages	Disadvantages	Comments
Kapton H	200°C	Yes	Lightweight. Excellent cut through resistance. Abrasion resistance. Minimal smoke generation. Not brittle when cold.	Arc-tracking. Hydrolytic instability. High moisture uptake. Subject to flashover.	Most widely used insulation material.
Tefzel Cross-linked Teflon	150°C	No	Lower moisture absorption than Kapton. Non-combustible gases when fails.	Weight and volume penalty compared to Kapton. Poor mechanical properties.	Navy has been replacing Kapton with Tefzel.
PTFE/ Polyimide Hybrids	220°C	No	Good balance of properties compared to Kapton and Tefzel. Performed better than MIL-W-81381 in MacAir tests.	Maximum use temperature. 15 percent weight penalty compared to Kapton.	Identified by MacAir program. Teledyne Thermatics has been recommended for inclusion in QPL.
Upilex-S	~250°C	Yes	Better thermal stability, arc-track resistance, and hydrolytic stability than Kapton.	Arc-tracking not eliminated. Non-domestic source. SiO_2 coating susceptible to abrasion etc.	Recommended by the TRW study.

TARGET FOR NEW INSULATION



FOSTER-MILLER APPROACH TO DEVELOP A 300°C RATED, ARC-TRACK RESISTANT AEROSPACE INSULATION

Large Classes of High Performance Polymers

Phase I Program

Evaluation Based on
- Structure
- Thermal Stability
- Electrical Properties

6 Materials

Phase II Step I

- Experimental Characterization
- Rank According to Performance

2 Materials

Phase II Step II

- Experimental Evaluations in Wire Configuration
- Selection Based on Performance and Commercialization Potential

One Material System for Consideration to Include in QPL

PHASE I PROGRAM

ADVANTAGES AND THE DISADVANTAGES OF KEY STRUCTURAL FEATURES

STRUCTURAL FEATURE	ADVANTAGES	DISADVANTAGES
Fluorine content	For low dielectric constant, low loss factor, high volume resistivity, uniform electrical properties over a wide range of temperatures and resistance to arc-tracking.	Aliphatic fluoropolymers, such as Tefzel, have poor mechanical properties at high temperatures. To overcome this limitation, must incorporate other features.
Liquid crystalline	Solvent resistance, high thermal stability, excellent electrical properties and possible improved resistance to arc-tracking.	Liquid crystalline polymers are difficult to process, need to incorporate additional features, e.g., polyimide.
Polyimide	High thermal stability, abrasion resistance, good electrical properties and good processability.	Poor resistance to arc-tracking. Improved through introduction of additional features, e.g., fluorinated groups, crystallinity.

ADVANTAGES AND THE DISADVANTAGES OF KEY STRUCTURAL FEATURES (continued)

STRUCTURAL FEATURE	ADVANTAGES	DISADVANTAGES
Aromatic	High thermal stability.	Highly aromatic polymers yield conducting char upon pyrolysis.
Rigidity/ stiffness	Rigidity increases thermal and mechanical capability, and reduces susceptibility to solvents.	Highly rigid polymers can be intractable, difficult to process, and low elongation to break. Some degrees of flexibility desired.
Cross-linking	X-linking significantly increases thermal stability. This process is widely used in the development of 371°C-rated composites.	X-linking greatly reduces flexibility, reduces elongation to break, and embrittles.
Carbon /hydrogen ratio	High carbon to hydrogen ratio increases thermal capability of polymers.	High carbon to hydrogen ratio may cause the formation of conductive char and susceptibility to arc-tracking.

CLASSES OF MATERIALS EVALUATED

- Organic Polymers
  - Polyimides
    - Thermoset polyimides
    - Thermoplastic polyimides
    - Fluorinated polyimides
    - Liquid crystalline polyimides
    - Fluorinated liquid crystalline polyimides
    - Siloxane imides
  - Liquid crystalline polymers
  - Lyotropic liquid crystalline polymers
  - Thermotropic liquid crystalline polymers
  - Polyquinolines
  - Polyphenylquinoxalines
  - Polyketones
  - Polyether ketones
  - Polyarylates
  - Polysulfones
  - Aromatic polyimides
  - Polyamide-imides
  - Polybenzimidazoles
  - Aliphatic fluoropolmers
- Blends of Organic Polymers
  - Polyimide blends with thermotropic liquid crystalline polymers
  - Polyimide blends with polyether sulfones
- Inorganic Materials
  - Polysilsesquioxanes
  - Polycarbosilane

SUMMARY GOALS AND ACHIEVEMENTS OF THE PHASE I PROGRAM

GOAL	ACHIEVEMENT
Establish insulation requirements	Thermal, electrical, mechanical and physical requirements established
Prepare an evaluation matrix to rank materials	Selection criteria to screen polymers developed: • Key structural features that contribute desired performance • Key electrical properties • Key thermal properties
Conduct screening tests	Eleven candidate materials were acquired and prepared for testing Dielectric measurements (25°C to 300°C, and 20 Hz to 1 MHz) on all available polymers with potential for 300°C were conducted
Select most promising materials	Six polymers have been identified with the potential for: • No arc-tracking • 300°C rating • Better hydrolytic stability than Kapton • Better mechanical properties and solvent resistance than Tefzel
Proposed strategy for implementation	A two step program to develop an insulation system for consideration to include in QPL: • Experimental investigation and ranking of performance to narrow the field to two • Evaluation in wire construction to select one material system on the basis of performance, cost and manufacturability
Conduct cost/benefit analysis	Deferred to Phase II

PHASE II
PROGRAM DETAILS

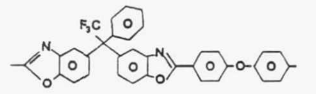
PERFORMANCE GOALS FOR SELECTED MATERIALS

- Arc-track resistance
  - >300 sec using ASTM D495
  - Concern: 0.125 in. thick samples
  - Develop alternate test for thin films
- Lifetime > 15,000 hr at 300°C
- Cost comparable to Kapton
- Amenable to manufacture into aerospace wire configurations on current equipment with little or no modification

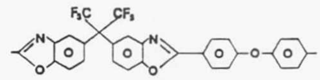
MATERIALS UNDER EVALUATION IN PHASE II

3F-PBO-PE	Fluorinated benzoxazole polyether
6F-PBO-PE	Thermoplastic fluorinated benzoxazole polyether
6F-PBO-PI	Fluorinated benzoxazole polyimide
36FDA-PDA	Fluorinated copolyimide
6FDA-PMDA-4BDAF	Fluorinated copolyimide
Low char polyimide	DuPont proprietary polyimide
Siloxane-polyimide	Polydimethylsiloxane polyimide
Phosphine oxide polymer	Poly(arylene ether phosphine oxide)
Xydar blends	Liquid crystal polyester

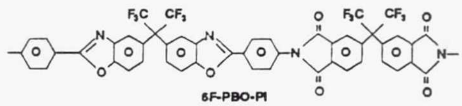
MOLECULAR STRUCTURES OF CANDIDATE POLYMERS



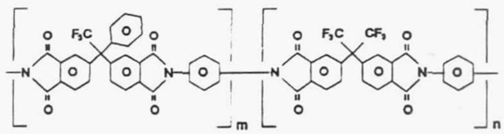
3F-PBO-PE



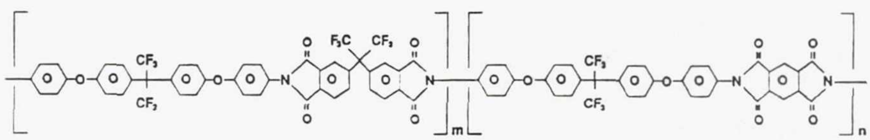
6F-PBO-PE



6F-PBO-PI

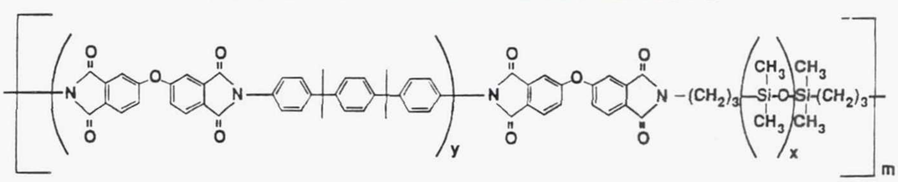


36FDA-PDA

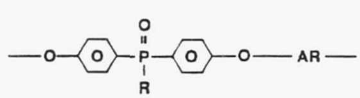


6FDA-PMDA-4BDAF

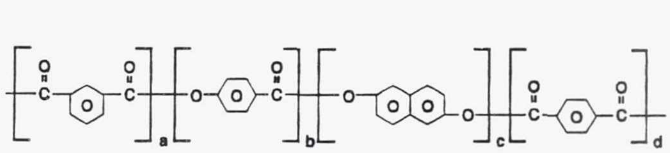
MOLECULAR STRUCTURES OF CANDIDATE POLYMERS



Siloxane Polyimide



Phosphine Oxide Polymer



A739-2

Xydar

CANDIDATE POLYMER PROPERTIES

POLYMER	SOURCE	Tg (°C)	PROPERTIES
3F-PBO-PE	Prof. J.E. McGrath VPI & SU Blacksburg, VA	299	5% wt loss at 547°C in air. Inherent viscosity (THF) = 0.80 Able to form 12 wt % solution in THF.
6F-PBO-PE	Daychem Laboratories Dayton, OH	290	Degradation onset in N_2 at 521°C. Able to form 18 wt % solution in THF.
6F-PBO-PI	Foster-Miller, Inc. Hoechst-Celanese	367	3% wt loss at 350°C after 64 hr. Dielectric constant (1MHz) = 2.82 Dissipation factor (1MHz) = 0.0004 Excellent solvent resistance.
36FDA-PDA	Foster-Miller, Inc. United Technologies	406	2% wt loss at 371°C after 100 hr in air. Films tend to be brittle with all p-PDA.

CANDIDATE POLYMER PROPERTIES

POLYMER	SOURCE	Tg (°C)	PROPERTIES
6FDA-PMDA-4BDAF	Prof. J.E. McGrath VPI & SU Blacksburg, VA	299	Using 30% 6FDA/70% PMDA ratio. 5% wt loss at 540°C in air. M_n = 30,000. Able to form 25 wt % PAA solution in DMAc.
Low char polyimide	DuPont	-	Able to form 14 wt % PAA solution in DMAc.
Siloxane - polyimide	Prof. J.E. McGrath VPI & SU Blacksburg, VA	-	34% PDMS (M_N = 4.5K) -66% polyimide (M_N = 11K) Able to form 20 wt % solution in $CHCl_3$ 52% PDMS (M_N = 4. 5K) -48% polyimide (M_N = 4K) Able to form 25 wt % solution in $CHCl_3$
Phosphine oxide polymer	Prof. J.E. McGrath VPI & SU Blacksburg, VA	245	R = ø and Ar = biphenyl 5% wt loss at 520°C in air.
Xydar	Amoco Performance Products	150	300 sec arc-track resistance. T_M = 348°C Dielectric constant (1MHz) = 2.8 Dissipation factor (1MHz) = 0.06

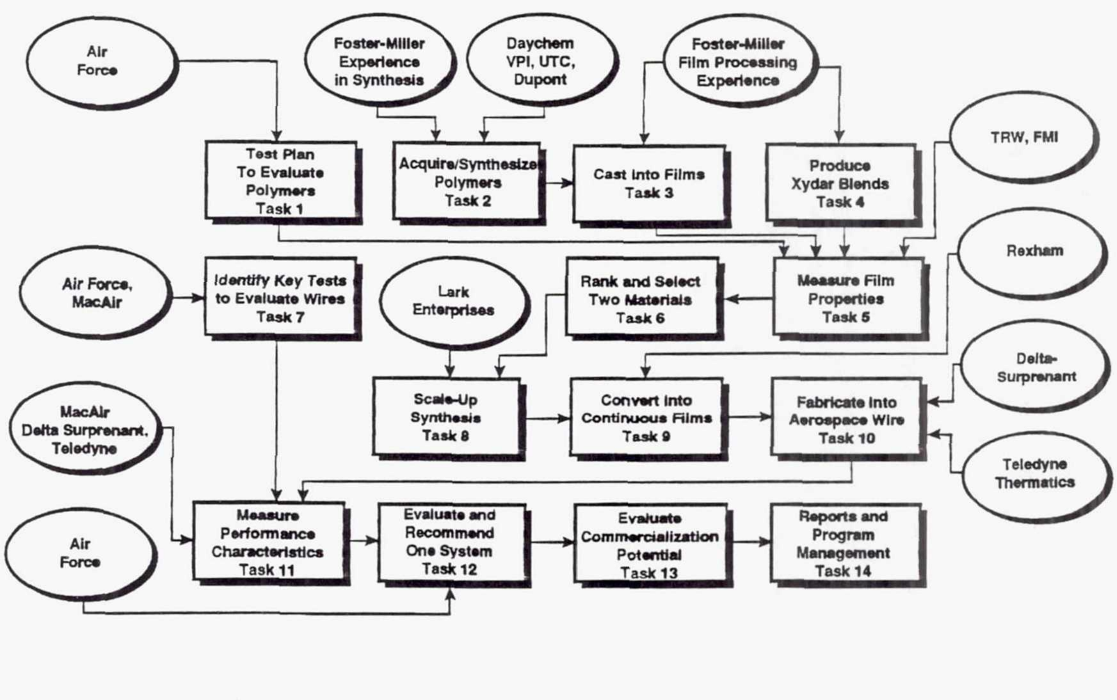
FILM PROPERTIES

- Measure properties of candidate polymers and Kapton using Air Force approved test plan
- Arc-track resistance tester built by Foster-Miller
- Proposed properties to be measured

THERMAL	ELECTRICAL	MECHANICAL	PHYSICAL
T_g T_m 5% weight loss	Dielectric constant Dissipation factor Dielectric strength Volume resistivity Surface resistivity Arc resistance*	Tensile strength, break Tensile strength, yield Tensile elong., break Tensile elong., yield Flexural modulus C.T.E.	Humidity resistance Water absorption after 24 hr Fluid immersion Aging stability

*Use ASTM D495 or alternative arc resistance test

DETAILED PROGRAM PLAN



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3M HIGH TEMPERATURE DIELECTRIC FILM

Edward Hampl, Jr.
3M Electrical Products Division
St. Paul, Minnesota

3M High Temperature Dielectric Film

Summary

* A high performance film product to over 200 ℃
* Excellent electrical properties to over 200 ℃
* Good mechanical properties
* Intriguing optical properties
* Excellent environmental & chemical properties
  - Low shrinkage to 300 ℃
  - Moisture insensitive
  - Low outgassing under vacuum
  - Excellent surface qualities - easy metallization of film
  - Flame retardant
  - Low smoke generation

3M FPE
High Temperature Dielectric Film

General Comments

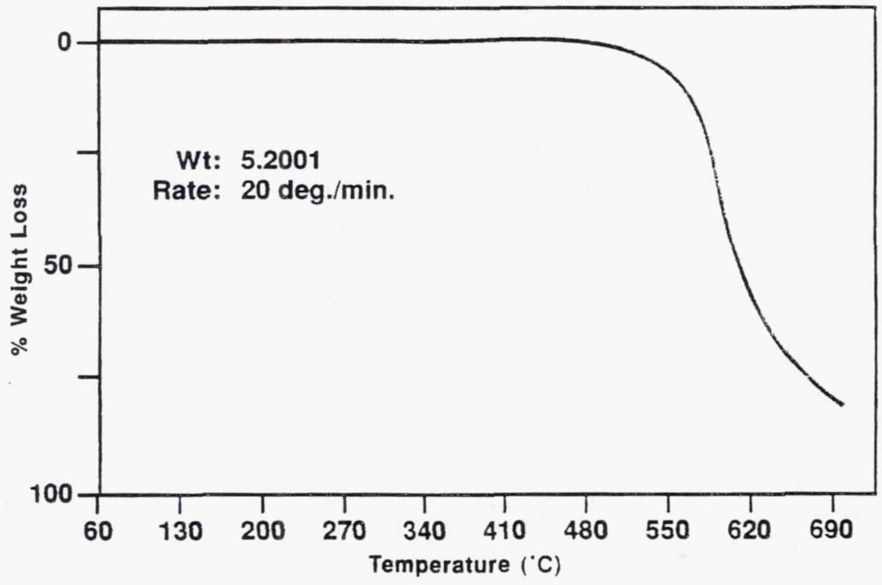
- High molecular weight polymer - 400,000 to 700,000
- Experimentally prepared film - caliper 5 μ to 400 μ
- Density - 1.22 g/cc
- Radiation stability measured to 400 megrads
- Easily metallized

3M FPE High Temperature Dielectric Film

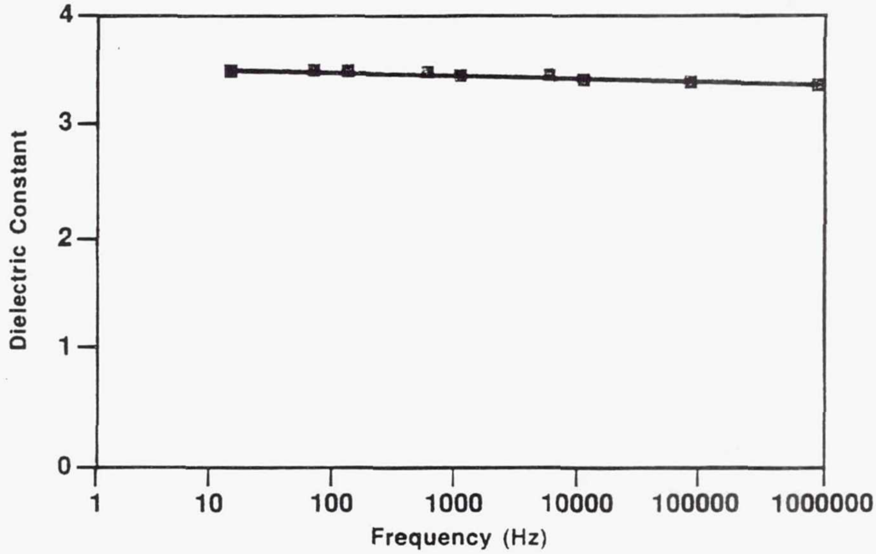
Thermal Properties

- High T_g - 335°C (DSC measurement)
- Thermal stability to 500°C (TGA measurement in air)
- Thermal conductivity - 0.13-0.15 watts/m K° (23°-150°C)
- Flame retardant - high limiting oxygen index, low smoke generation, high ignition temperature, high char yield, no drip and/or ignition when exposed to flame
- Low shrinkage - <0.2% at 200°C/24 hours
  - 1% at 200°C/2000 hours
  - <0.3% at 250°C/10 hours

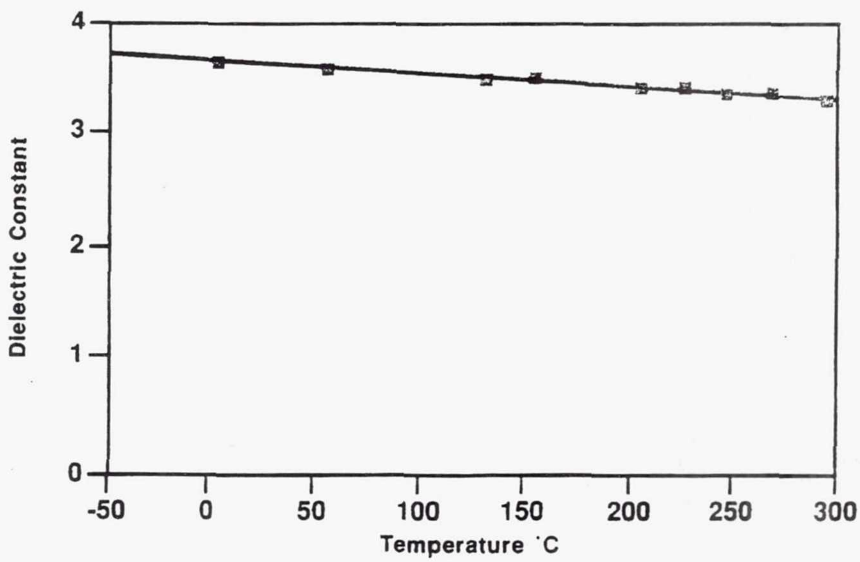
FPE High Temperature Dielectric Film



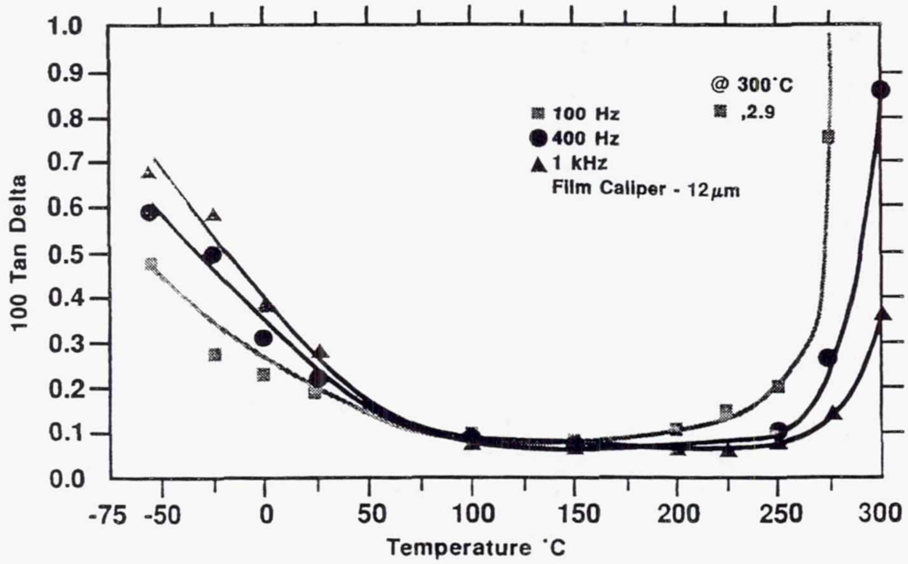
Dielectric Constant as a Function of Frequency - 3M FPE Film (25°C - 3M Data)



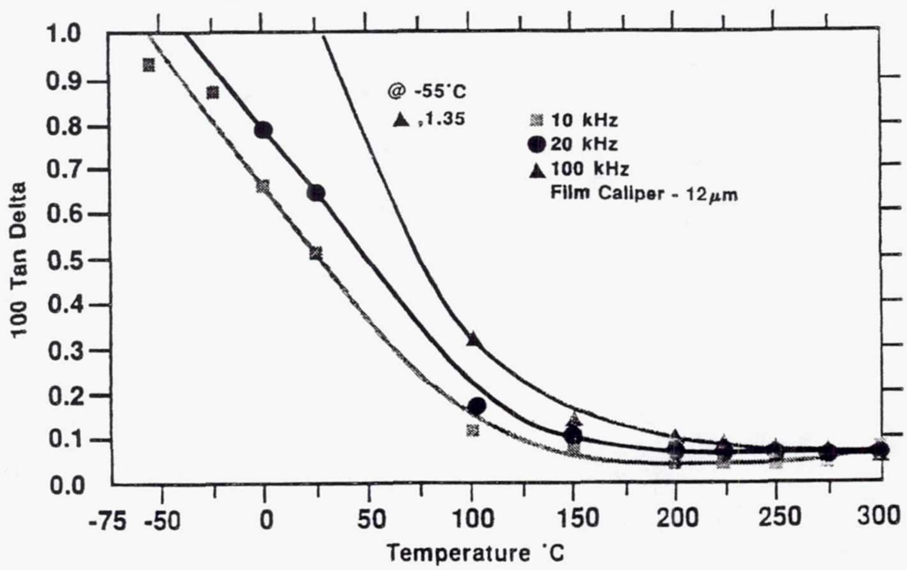
Dielectric Constant as a Function of Temperature - 3M FPE Film (1 KHz - 3M Data)



3M FPE Film Dissipation Factor as a Function of Temperature (100 Hz to 1 KHz)



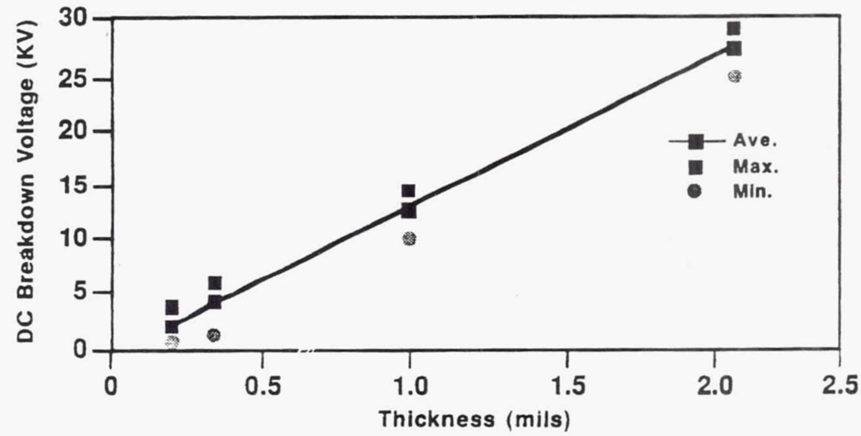
3M FPE Film Dissipation Factor as a Function of Temperature (10 KHz to 100 KHz)



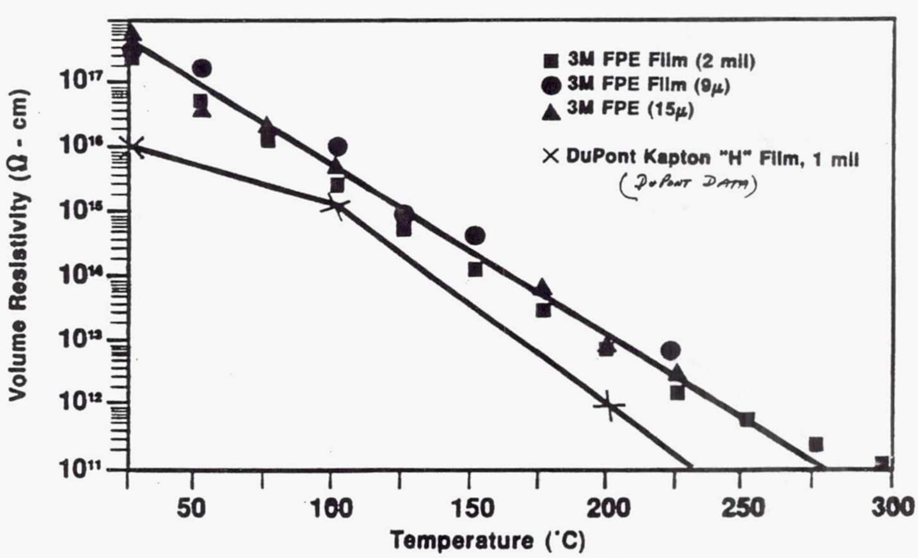
3M FPE Film Breakdown Voltage (D.C.) as a Function of Thickness

Test Conditions:

- **Measurement in air at ambient conditions**
- **Voltage rise 250 V/sec.**
- **Each data point is average of 36 measurements**
- **Electrodes: 0.25 inch diameter brass deadweight, rounded edges**



Volume Resistivity as a Function of Temperature 3M FPE and DuPont Kapton Film



Comparative DC Dielectric Strength of Insulation Films

Film	DC dielectric strength @ 1 mil, 25°C, air (KV/mil)
3M FPE	12.3
PET	7.5
Polyimide	7.0
PTFE	4.2

3M FPE High Temperature Dielectric Film

Mechanical Properties

(Measurements to 300°C)

- **Tensile strength - 20,000 psi (22°C)**
- **Elongation - 70% (22°C)**
- **Modulus of elasticity - 500,000 psi (22°C)**
- **High heat distortion temperature - <<<1% (21°C - 300°C; 50 psi load), 1% (21°C - 300°C; 300 psi load)**
- **Coefficient of expansion C(α) - 4×10^{-5} m/m/°C**

3M FPE High Temperature Dielectric Film

Chemical Properties

- **Humidity coefficient C(ß) - 0.4×10^{-5}(m/m/%RH)**
- **Moisture absorption <0.6% (50% RH, 23°C, 24 hrs)**
- **Very low outgassing under high vacuum - insignificant at 10^{-7} torr, at least a factor of 10 lower than polyimide**
- **Non-toxic by 3M testing**
- **Low toxic gas generation - no N, S, or X in chemical structure**
- **Compatible with common impregnants, weak acids, and weak bases - Fluorochemicals, Silicone oil, Castor oil, Monoisopropyl biphenyl, Ditolyl ether, Tricresyl phosphate, Phenyl xylyl ethane**

Thermal Aging and Hydrolytic Stability Test Results

(WPAFB Contract F44615-88-C2913)

Aging Environment	Meas. Temp. (°C)	Dissipation Factor 100 Hz	400 Hz	1 kHz	10 kHz
Ambient	25	0.0020	0.0021	0.0026	0.0053
Air, 7 days, 300°C	25	0.0025	0.0024	0.0029	0.0046
N_2, 7 days, 300°C	25	0.0022	0.0021	0.0026	0.0046
H_2O, 2 days, 100°C	25	0.0018	0.0019	0.0025	0.0045
Ambient	225	0.0014	0.0006	0.0006	0.0004
Air, 7 days, 300°C	225	0.0012	0.0007	0.0008	0.0008
N_2, 7 days, 300°C	225	0.0008	0.0003	0.0004	0.0005
H_2O, 2 days, 100°C	225	0.0009	0.0003	0.0004	0.0003

3M FPE High Temperature Dielectric Film

Optical Properties

- **Optically transparent; colorless, water white, haze 0.1%**
- **High index of refraction polymers - 1.656**
- **Very low coefficient of birefringence - 0.0003**
- **Good U.V. stability - self-stabilizing mechanism**
- **Transmissions 90-95% from 350 nanometers through 2~~nm~~** MICRONS

Suggested Applications

- Electrical insulation - class F/H/C
- Capacitor film high temperature, high energy density, pulse power, surface mount
- Wire and cable insulation
    - **Electrical power and signal wire film wrap**
    - **Fiber optic cable wrap**
    - **Magnet wire film wrap**
    - **Magnetic filament cable wrap**
- Conformal coatings
- Substrate
    - **Electronic packaging**
    - **Thin film depositions for opto-electronic and magnetic product applications**

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REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 1994	Conference Publication

4. TITLE AND SUBTITLE

Second NASA Workshop on Wiring for Space Applications

5. FUNDING NUMBERS

WU–323–57–4A

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E–8294

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, D.C. 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA CP–3244

11. SUPPLEMENTARY NOTES

Proceedings of a workshop cosponsored by NASA Headquarters, Office of Safety and Mission Quality and NASA Lewis Research Center, Cleveland, Ohio, October 6–7, 1993. Compiled by Ahmad Hammoud and Mark Stavnes, Sverdrup Technology, Inc., Lewis Research Center Group, 2001 Aerospace Parkway, Brook Park, Ohio 44142 (work funded by NASA contract NAS3–25266). Responsible person, Ahmad Hammoud, organization code 5430, (216) 433–8511.

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Unclassified - Unlimited
Subject Categories 05 and 18

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

This document contains the proceedings of the Second NASA Workshop on Wiring for Space Applications held at NASA Lewis Research Center in Cleveland, Ohio, October 6–7, 1993. The workshop was sponsored by NASA Headquarters Code QW Office of Safety and Mission Quality, Technical Standards Division and hosted by NASA Lewis Research Center, Power Technology Division, Electrical Components and Systems Branch. The workshop addressed key technology issues in the field of electrical power wiring for space applications. Speakers from government, industry and academia presented and discussed topics on arc tracking phenomena, wiring system design, insulation constructions, and system protection. Presentation materials provided by the various speakers are included in this document.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Insulation; Space wiring; Wiring constrictions; Arc tracking; Polyimides	225
	16. PRICE CODE
	A10

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	